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of the

American Fisheries Society

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SEVENTY-SIXTH ANNUAL MEETING
SAINT PAUL, MINNESOTA
SEPTEMBER 11, 12 AND 13, 1946

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AMERICAN FISHERIES SOCIETY

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THE AMERICAN FISHERIES SOCIETY

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[1] Mail should be addressed to George E. Sprecher, Wisconsin Conservation Department, Madison 2, Wisconsin. Mr. Sprecher was elected Secretary-Treasurer at the Seventy-eighth Annual Meeting.

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[1] Deceased; Mr. Gottschalk acted as Chairman of the Committee.

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The first meeting of the Society occurred December 20, 1870. The organization then effected continued until February, 1872, when the second meeting was held. Since that time there has been a meeting each year, as shown below. The respective presidents were elected at the meeting, at the place, and for a period shown opposite their names, but they presided at the subsequent meeting.

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5.	Robert B. Roosevelt	1875-1876	New York, N. Y.
6.	Robert B. Roosevelt	1876-1877[1]	New York, N. Y.
7.	Robert B. Roosevelt	1877-1878	New York, N. Y.
8.	Robert B. Roosevelt	1878-1879	New York, N. Y.
9.	Robert B. Roosevelt	1879-1880	New York, N. Y.
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20.	Eugene G. Blackford	1890-1891	Put-in-Bay, Ohio
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28.	George F. Peabody	1898-1899	Omaha, Nebr.
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34.	Henry T. Root	1904-1905	Atlantic City, N. J.
35.	C. D. Joslyn	1905-1906	White Sulphur Springs, W. Va.

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[1] A special meeting was held at the Centennial Grounds, Philadelphia, Pa., October 6 and 7, 1876.

36. E. A. Birge	1906-1907	Grand Rapids, Mich.
37. Hugh M .Smith	1907-1908	Erie, Pa.
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46. George W. Field	1916-1917	New Orleans, La.
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50. Nathan R. Buller	1920-1921	Ottawa, Canada
51. William E. Barber	1921-1922	Allentown, Pa.
52. Glen C. Leach	1922-1923	Madison, Wis.
53. George C. Embody	1923-1924	St. Louis, Mo.
54. Eben W. Cobb	1924-1925	Quebec, Canada
55. Charles O. Hayford	1925-1926	Denver, Colo.
56. John W. Titcomb	1926-1927	Mobile, Ala.
57. Emmeline Moore	1927-1928	Hartford, Conn.
58. C. F. Culler	1928-1929	Seattle, Wash.
59. David L. Belding	1929-1930	Minneapolis, Minn.
60. E. Lee LeCompte	1930-1931	Toronto, Canada
61. James A. Rodd	1931-1932	Hot Springs, Ark.
62. H. S. Davis	1932-1933	Baltimore, Md.
63. Fred A. Westerman	1933-1934	Columbus, Ohio
64. E. L. Wickliff	1934-1935	Montreal, Canada
65. Frank T. Bell	1935-1936	Tulsa, Okla.
66. A. G. Huntsman	1936-1937	Grand Rapids, Mich.
67. I. T. Quinn	1937-1938	Mexico City, Mexico
68. Fred J. Foster	1938-1939	Asheville, N. C.
69. T. H. Langlois	1939-1940	San Francisco, Calif.
70. James Brown	1940-1941	Toronto, Canada
71. John Van Oosten	1941-1942	St. Louis, Mo.
72. John Van Oosten	1942-1943	(No meeting.)[2]
73. John Van Oosten	1943-1944	(No meeting.)[3]
74. John Van Oosten	1944-1945	(No meeting.)[3]
75. John Van Oosten	1945-1946	(No meeting.)[3]
76. Joe Hogan	1946-1947	St. Paul, Minn.

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[2] The annual meeting scheduled to be held in New Orleans, La., was cancelled because of the war emergency.

[3] No annual meeting scheduled because of the war.

In Memoriam

Adams, William C., Albany, N. Y.

Belmont, Perry, Washington, D. C.

Buller, Nathan R., Harrisburg, Pa.

Cobb, Eben W., St. Paul, Minn.

Dean, Herbert D., Northville, Mich.

Folger, J. A., San Francisco, Calif.

Fortmann, Henry F., San Francisco, Calif.

Foster, Frederick J., Seattle, Wash.

Foster, George M., Woods Hole, Mass.

LeCompte, E. Lee, Baltimore, Md.

Low, Ethelbert I., New York, N. Y.

Mailliard, Joseph, San Francisco, Calif.

Morton, W. P., Providence, R. I.

TABLE OF CONTENTS

Page

List of officers 3

Committees 4

Past presidents 6

In Memoriam 8

PART I PAPERS

Current trends in state fishery programs. *George J. Eicher, Jr.* 13

Relation of dissolved oxygen to winter mortality of fish in Michigan Lakes. *Gerald P. Cooper* and *George N. Washburn.* 23

The vitamin B requirement of trout. *Arthur M. Phillips, Jr.* 34

Experiments with combinations of largemouth black bass, bluegills, and minnows in ponds. *H. S. Swingle.* 46

The rate of growth and sex ratio for seven Michigan fishes. *William C. Beckman.* . 63

Dosage of sulfamerazine in the treatment of furunculosis in brook trout, *Salvelinus fontinalis. James S. Gutsell* and *S. F. Snieszko* 82

The Eastern Belted Kingfisher, *Megaceryle alcyon alcyon* (Linnaeus), in relation to fish management. *J. Clark Salyer II* and *Karl F. Lagler* 97

Fishery conservation through education. *R. T. Whiteleather.* 118

Trends in the lake trout fishery of Lake Huron through 1946. *Ralph Hile* 121

Recent investigations on the sea lamprey, *Petromyzon marinus,* in Ontario. *H. H. MacKay* and *Earl MacGillivray* 148

A brief history of the sea lamprey problem in Michigan waters. *David S. Shetter* 160

Localized weed control in management of game fish. *George J. Eicher, Jr.* 177

The control of aquatic plants with fertilizers in rearing ponds at the Lonoke Hatchery, Arkansas. *Joe Hogan* 183

Rates of survival and growth of bluegill yolk fry stocked at different intensities in hatchery ponds. *Louis A. Krumholz* 190

Fish populations of some Minnesota trout streams. *Lloyd L. Smith, Jr., Raymond E. Johnson,* and *Laurence Hiner* 204

The age, growth, and distribution of the longjaw cisco, *Leucichthys alpenae* Koelz, in Lake Michigan. *Frank W. Jobes* 215

The effects of deflectors in a section of a Michigan trout stream. *David S. Shetter, O. H. Clark,* and *Albert S. Hazzard* 248

Cooperative fishery survey of the upper Mississippi River. *Lloyd L. Smith, Jr.*.. 279

A definition of depletion of fish stocks. *John Van Oosten* 283

The statistical analysis of creel-census data. *Charles M. Mottley* 290

An analysis of the feeding habits of rainbow trout and lake trout in Birch Lake, Cass County, Michigan. *J. W. Leonard* and *F. A. Leonard* 301

Page
Relative toxicity of suspension and oil formulations of DDT to native fishes in Back Creek, West Virginia. *Eugene W. Surber* and *Dorothy D. Friddle* 315
Some indices of lake productivity. *John B. Moyle* 322
Development and status of pond fertilization in central Europe. *John C. Neess* .. 335

PART II SYMPOSIUM

MISSOURI RIVER BASIN—FLOOD CONTROL, NAVIGATION, AND IRRIGATION AND THEIR RELATION TO FISH AND GAME

Recreational features of Missouri River development program. *Brig.-Gen. Lewis A. Pick* 361
Program and policies of the United States Bureau of Reclamation. *William G. Sloan* 373
Missouri River basin development and its effects on fish and wildlife. *Clarence Cottam* 380

PART III BUSINESS SESSIONS

Agenda of seventy-sixth annual meeting 391
Opening remarks of the president 392
Appointment of sessional committees 394
Reports of officers 395
  Secretary-treasurer 395
  Vice-president, Division of Fish Culture 398
Presentation by Mr. Seth Gordon of photograph of members in attendance at 1915 meeting of the Society 401
Reports of standing committees 404
  International relations 404
  State and national relations 417
  Common and scientific names of fishes 419
  Publications 421
Reports of special committees 425
  Pollution study 425
Reports of sessional committees 433
  Time and place 433
  Auditing 433
  Resolutions 434
  Nominations 440
Concluding business 443

APPENDICES

Instructions for preparing manuscripts for the Transactions of the American Fisheries Society 447
List of members 451
Index 467

Part 1

Papers

CURRENT TRENDS IN STATE FISHERY PROGRAMS

GEORGE J. EICHER, JR.
U. S. Department of the Interior, Fish and Wildlife Service
Seattle, Washington

ABSTRACT

A questionnaire survey of the various states was made in June of 1946 to determine the current trends in fishery programs. Trout states total 31, with 246 hatcheries producing 203,546,000 fry and fingerlings and 18,081,000 creel-sized trout. The trend is to more creel-sized trout. States take 194,000,000 eggs themselves and obtain 98,375,000 trout eggs from other sources. A majority of states classify results of fry plantings as poor and of creel-sized plantings as good.

The average creel-size trout is 7½ inches in length and is 13.2 months old. The cost per pound for food alone averages 14.6 cents. Total cost per pound for raising trout averages 66 cents. Rainbow trout constitutes 47.5 percent of all trout raised, followed by cutthroat, 15 percent; lake trout, 13.4 percent; brook, 12.2 percent; and brown, 11 percent.

Hatchery disease loss averages 13.5 percent. Gill disease seems most prevalent. The principle trout-culture problem is food, either procurement or proper diet selection. Floods and low water cause greatest loss of trout on fishing grounds. Public access to fishing grounds seems the principal trout management problem. Pond fish cultured by 26 states totaled 880,281,000, but 21 of 36 states stated that they did not think the planting of pond fish advisable in waters in which a resident population was present. Of 37 states, 34 had problems of overpopulation in pond-fish waters. Most of them were fighting it by removing restrictions on fishing. The 48 states sell 8,280,000 fishing licenses for $10,580,000. Average license fee in trout states is $1.75 and in non-trout states $1.28. Of 40 states reporting, 29 have intensive statewide management programs for fishing waters. In the 35 states reporting on numbers of men employed in various lines of fisheries, a total of 98 men are in administrative posts, 214 are in biological work, 741 in trout culture, 271 in pond-fish culture and 318 in other lines of work allied with fisheries.

INTRODUCTION

In June 1946, the writer, acting for the Arizona Game and Fish Commission, sent out a questionnaire to the various states to determine current trends in fishery programs and thinking along various fishery lines. These questionnaires were divided into three sections: trout, pond fish, and general questions.

The questions on trout were as follows: Do you engage in trout culture? Number of hatcheries in operation. Number of fry and fingerlings planted annually. Number of creel-sized trout planted. Number of eggs you take yourselves. Number of eggs from commercial hatcheries and elsewhere. Number of each species planted. How would you rate your success in planting fry in lakes—in streams?

At what length do you plant your legal-sized trout? At what age do they reach this size? What is your cost per pound for food alone of trout reared? What is your total cost per pound for all expenditures exclusive of new construction? What is the composition of your normal fingerling diet? From what diseases do your trout suffer most? What is your annual percentage of disease loss? What is your principal problem in trout culture? From what causes do you suffer most loss on your trout waters? What is your principal problem in management of trout waters?

Questions on pond fish were as follows: Do you culture pond fish (black bass, bluegill, catfish, etc.)? Numbers of pond fish produced annually. Do you consider the planting of these species economically and biologically advisable in waters other than those in which a present population is nonexistent? Have you problems of overpopulation in pond-fish waters? Are they serious? What solutions have you developed to combat such situations? What are your principal problems in pond-fish management?

General questions were as follows: How many fishing licenses do you sell annually? Cost of license. Have you a program of intensive statewide biological management of your fishing waters? What type of work does it include? Numbers of men employed in your fish division for administration, biological management, trout culture, pond-fish culture and any other. Comments.

The way in which the questionnaires were returned was an indication in itself of the attitudes of various state departments toward questionnaires in general. Five did not return questionnaires at all, but 24 filled them out in full as much as concerned them. Of these 24, some went to very great effort to make the answers accurate and complete. One even went so far as to type out a larger copy of the questionnaire so as to accommodate longer answers. A few filled them in very sketchily. The results in general, however, give a better-than-average cross-section of the country's state fishery programs. The five states not replying were those in which one would not expect to find a very extensive fishery program; so the value of the compilation is probably not greatly affected. It is possible that their lack of fisheries had some bearing on their failure to answer.

TROUT CULTURE

Of the states reporting, 31 are trout states, of which 29 have hatcheries of their own (Table 1). They operate a total of 246 trout hatcheries or an average of 8.5 per state. The total number of fry and fingerlings produced is 203,546,000 for an average of 6,720,000 per state. Total production of creel-sized fish was 18,081,000 for an average of 620,000 per state. Of interest is the greatly increased trend to creel-sized trout. It is the recollection of the writer that it was but some 12 years ago that a few states embarked on programs of rearing trout large enough to satisfy the angler at the time of planting. Now we find that 28 out of 31 states are producing large numbers of catchable fish, 8 of them distributing over a million each year. Five states report planting only catchable trout and only three plant no large fish. The State of Washington leads in production of large-sized trout with 2,500,000, followed by Utah and New York with 2 million each. In the fry and fingerling category, the State of Washington produces 49 million. Three smaller states produce no trout themselves, but plant small numbers obtained elsewhere.

Of interest is the way in which the various states obtain their eggs for hatching. Some 194,000,000 eggs were taken by the states themselves. Probably more than half of these were from wild stock (some states volunteered the information as to the number taken from brood stock, and it would probably represent more than a third of the take) but since this breakdown was not asked for, no compilation can be made. The average number of self-taken eggs per state was 7,500,000. Eggs from elsewhere totaled 98,375,000 for an average of 3,500,000 per state. Approximately half of these were from commercial hatcheries and the remainder from the federal government. Five states take no eggs themselves, and four states take all of their own eggs. The State of Washington leads in egg-taking, with 60 million, followed by California with 23 million, and Oregon with 22 million. Two states did not report figures, stating "all" and "none" in each column.

The reason for the emphasis on creel-sized trout might be found in the thinking with respect to the planting of small and large trout in lakes and streams. Only 3 states reported good success with fry in streams, 9 reported fair success, and 13 classified results of fry planting in streams as poor. More states consider fry planting in lakes a better gamble, as 5 claimed good success in this column, 8 fair success, and only 9 classed results as poor. However, of states planting legal-sized trout in lakes, 19 reported good success, 2 had fair success, and only 1 classed the returns from planting legal-sized trout in lakes as poor. The picture for the introduction of creel-sized trout in streams is even better, as results were considered good by 23 states, fair by only 3, and poor by none.

The average creel-sized trout in 28 states is slightly over 7½ inches long and is 13.2 months old. As with other categories, there seems to be considerable variation among the states here. The creel size runs all the way from 6 to 16 inches and the time required to rear the average 7½-inch trout runs from 6 to 24 months.

In costs per pound for food alone and costs per pound for all expenses there seems to be an unwarranted divergence. It seems likely that some replies possibly were guesses or misinterpretations of the questions. Many did not report at all; however, of 18 reporting on costs per pound for food alone, the answers ranged from 3 cents to 3 dollars, averaging 14.6 cents. Total costs ranged from 24 cents to $4.50 per pound and averaged 66 cents.

TABLE 1.—*A summary of the scope and cos*

[Where no entry was made a reply was not

State	Number of hatcheries	Fry and fingerlings stocked annually (thousands)	Creel-size trout stocked annually (thousands)	Annual egg collection (thousands)	Eggs procured from outside sources (thousands)	Success of planting fry in lakes
Arizona	3	900	350	0	3,000	Good
California	22	14,500	1,500	23,000	3,000	Fair
Colorado	22	3,379	1,591	750	6,000	Fair
Connecticut	4	780	549	0	1,150	Poor
Georgia	1	0	100	0	225	–
Idaho	15	19,000	25	20,000	5,000	Fair
Illinois	0	20,000	0	–	–	–
Iowa	2	0	120	0	all	None
Kansas	1	600	0	–	–	–
Kentucky	0	0	4	–	–	None
Maine	25	6,000	1,000	4,000	3,000	Fair
Maryland	4	200	68	0	500	Poor
Massachusetts	5	350	500	1,500	0	–
Michigan	14	7,000	870	–	–	–
Minnesota	3	1,000	150	1,500	500	Poor
Missouri	–	250	100	all	0	–
Montana	11	13,000	0	20,000	2,000	Fair
Nebraska	2	200	52	200	200	Poor
Nevada	4	3,000	0	500	2,500	Fair
New Hampshire	6	2,000	636	2,000	3,000	?
New Mexico	5	2,136	225	400	4,000	Fair
New York	20	6,000	2,000	9,000	3,600	Poor
North Carolina	4	150	100	50	700	–
Oregon	14	15,000	1,000	22,000	5,000	Good
Pennsylvania	4	1,982	1,575	5,000	2,000	–
Rhode Island	1	0	70	200	0	–
Tennessee	0	0	55	0	0	–
Utah	12	18,500	2,000	12,000	13,000	Good
Vermont	5	2,750	550	2,000	4,500	Poor
Washington	21	49,269	2,500	60,000	15,000	Good
West Virginia	3	1,000	200	0	1,250	Poor
Wisconsin	13	5,000	500	7,000	0	Good
Wyoming	7	8,000	50	3,000	9,000	Fair

Of 24 states reporting on fingerling diets, 9 feed principally liver and heart, 8 lungs and melts, 5 horse meat, and 2 fish. Most hatcheries use meals of some sort, either protein concentrates or cereals.

The rainbow trout seems to be the favorite species reared in hatcheries by the various states, as 78,141,000 are produced annually. They are followed well down by 24,750,000 cutthroat trout, 22,530,000 lake trout, 20,323,000 brook trout, and 18,340,000 brown trout. Other salmonoids included 4,730,000 grayling, mostly planted by the western states and 40 million Kokanee or landlocked sockeye salmon stocked by Idaho, Washington, and Oregon.

Disease loss (Table 2) ranged from 0 to 60 percent and averaged 13.5 percent. Gill disease seems to be the worst offender, with 12 states reporting it first. Five were troubled with fin rot and *Octomitus*, 4 have *Gyrodactylus*, 3 furunculosis, 2 ulcer disease, and 1 costiasis.

Losses on fishing waters vary considerably. Of 26 states reporting, 6 listed floods first, 6 low water, 4 natural enemies, 3 winterkill, 2 pollution, 2 "not known," 1 illegal fishing, and 1 alkalinity. Also listed were over-

erations as reported by the various states

ted that did not reply or do not plant trout]

of e t	Success of planting creel-size trout in streams	Average length of creel-size trout when planted (inches)	Average age of creel-size trout when planted (months)	Cost of food per pound of fish reared (dollars-cents)	All costs exclusive of new construction per pound of fish reared (dollars-cents)	Chief constituents of fingerling diet
	Good	8	18	0.18	0.90	Horse meat; cereals
	Fair	6– 8	6– 8	–	0.94	Fresh fish; liver
	Good	8–10	13–14	0.03	0.57	Carp, meal, 9:1 ratio
	Fair	9	12–24	0.62	1.50	Lungs; melts; hearts
	Good	7	8–10	–	–	Hearts; liver
	?	6–10	12	–	–	Liver; horse meat; fish
	–	–	–	–	–	—
	Good	7–10	15–18	–	0.24	Meals; liver
	–	–	–	–	–	—
	Good	7– 9	–	–	–	—
	Good	8–12	–	–	–	Meals, blood
	Good	8	12	–	0.45	Hearts; liver
	Good	6– 9	12–18	–	–	Melts; fish meal
	–	–	–	–	–	—
	Good	7– 9	15–18	0.20	0.60	Melts; cereal
	–	10	15–18	–	–	—
	–	–	–	1.00	1.50	—
	Good	8–12	14	0.18	0.45	Liver, U.S. No. 6
	–	–	–	–	–	—
	Good	6– 8	8–12	0.25	–	Melts; dog meal
	Good	7	6–12	0.06	0.89	Horse meat; rough fish
	Good	7	12	0.28	0.75	Meat, meal, 7:4 ratio
	Good	7	12–24	0.25	1.50	Speel; dog meal; cereals
	Good	6–10	12	0.10	0.50	Lungs; liver; fish
	Good	9	–	–	0.55	Liver; fish
	Good	7–16	12–24	0.05	–	Melts; fish
	Good	7	12	–	–	Liver; dog food
	Good	7	11	0.04	0.75	Horse meat; carp; meals
	Good	6	8–12	–	0.55	Horse meat; melts; meals
	Good	6– 8	10–14	–	0.55	Liver; fish meal; fish
	Good	8	15	–	–	Melts; fish meal
	Good	7– 9	16	0.09	0.56	Canned carp; melts
	Fair	7	12	0.20	0.70	Horse meat; kibbers; Balto

stocking, *Gyrodactylus,* ulcer disease, furunculosis, and diversion into canals.

Food, either the procurement of it or the proper type, seems to constitute the main fish-cultural problem. Ten states listed procurement of food as their main fish-production problem, 5 need proper diets, 3 lack space, and 2 listed lack of trained personnel. It is highly probable that administrators of almost every state lack trained personnel, but feel it to be such a common or unavoidable problem that they did not bother to list it. Two states reported the happy state of affairs of having no fish-cultural problems.

In the management of trout waters, the leading problem was that of obtaining access to waters, with 5 states complaining of this difficulty. Four listed lack of information as their principal stumbling block. Probably more have this problem than reported it. Three listed diversion first, 2 law enforcement, 2 floods, 2 weeds, and 1 overstocking. Some listed heavy fishing pressure, but this is a problem that every state has today and is more or less the root of all of our fishery problems.

TABLE 2.—*A summary of trout-management problems and policies reported by state fishery administrations*

[Where no entry was made a reply was not received. State omitted that sent no information on points listed]

State	Chief disease in trout hatcheries	Percentage loss from disease	Chief source of loss in fishing waters	Chief problems in trout culture	Chief problems in trout management
Arizona	*Octomitus;* costiasis; gill disease	10	Alkalinity; winter-kill	Food; space	Lack information
California	*Octomitus; Gyrodactylus*	5	Floods	Food	Lack information
Colorado	*Octomitus; Gyrodactylus*	28	Furunculosis	Space	Posted lands
Connecticut	Red spot; furunculosis	50	Water fluctuation	Lack of water	—
Georgia	Parasites	1	Illegal fishing	Cleanliness	Law enforcement
Idaho	Fin rot; gill disease	–	Predators, overstocking	—	—
Iowa	Fin rot	small	Floods	None	Floods; access
Maine	*Chilodon; Gyrodactylus*	–	None	Food	Overstocking
Maryland	—	–	None	Food	Lack water
Massachusetts	External parasites	–	Water fluctuations	More fish	—
Minnesota	Gill disease	small	Floods	Food	—
Montana	Gill disease	–	Irrigation	Food	Irrigation
Nebraska	Gill disease	small	Floods	Food	Floods; access
Nevada	None serious	–	Low water	Money	Diversion
New Hampshire	Ulcers; gill disease; *Gyrodactylus*	5–10	Predators	Food	Food supply
New Mexico	Gill disease	5	Natural enemies	Personnel[1]	Overgrazed shores
New York	Gill disease; ulcer disease	20	Ulcer disease	Food	Changing waters
North Carolina	Fungus; fin rot *Octomitus*	10	Floods	Water supply	Protection
Oregon	Parasites; furunculosis	5–10	Some winter-kill	Food; disease	Trash fish; weeds
Pennsylvania	Few	?	Not known	Food costs	Drought
Rhode Island	Furunculosis; fin rot	25–60	Not known	—	Access
Tennessee	None	–	Floods	None	Lack information
Utah	Gill disease; dietary	5	Low water; winter-kill	Food	Winter-kill
Vermont	Gill disease; *Octomitus*	?	Pollution	Food	Heavy fishing
Washington	Dietary	–	—	Food	Mixed populations
West Virginia	Gill disease	1	Drought	Food	Public relation
Wisconsin	Gill disease; parasites	10	Predators; pollution	Space	Pollution; erosion
Wyoming	Fin rot; popeye; gill disease	10	Diversion	Personnel[1]	Lack information

[1] Lack of trained personnel cited as chief problem in trout culture operations

POND-FISH CULTURE

In all, 880,281,000 pond fish were cultured by 25 states, the bulk of these, or 771,000,000, by Minnesota alone, which has since reported reduction of pond-fish operations (Table 3). The culture of pond fish seems to be a somewhat delicate subject and one in which pressure from sportsmen probably plays a heavy part. One state reported that it is discontinuing the production of pond fish except for the stocking of new waters or those in which the population had been removed by some catastrophe. Some others reported that they were trying to educate the public to the fact that artificial stocking with pond fish is seldom the answer to better fishing.

The answers to the questions on the advisability of planting pond fish in waters in which a resident population is present give us a key to thinking on this point. Of 36 states reporting on this question, 21 stated that they did not think the planting of pond fish in producing waters was advisable. Five thought such plantings of doubtful value, 3 indicated that in some cases it might be of value, and only 7 believed it worthwhile. One state which said "no" in general thought that for black bass the answer was "yes." It is interesting to note that 20 of the 26 states producing pond fish either answered "no" to this question or registered doubt as to the value of plantings. Evidently, as with some of our other time-honored fish and game practices which we are finding faulty, it is a "bear-by-the-tail" proposition in which misguided public opinion is a source of great pressure.

Closely allied to the question of pond-fish production is that of overpopulation in pondfish waters. Of 37 states reporting, 34 signified that they had overpopulation problems on pond fish. The three that reported no overpopulations were all situated in the southeast.

Methods of combatting overpopulation varied, with 14 fighting it by removal of restrictions on fishing for warm-water species. The surer method of removing entire populations from waters by poisoning or draining and then restocking on a sounder basis is employed by 16 states. One state listed weed control as a remedial measure and two simply listed better management.

The outstanding pond-fish problem seems to be population balance, as 8 states reported this first. Other problems of seemingly lesser importance were weeds, lack of information, lack of management, and winterkill.

GENERAL OPERATIONS

In order to make the figures on license sales complete, this information was taken from the U. S. Fish and Wildlife Service compilations (Table 4). They show that 8,280,000 fishing licenses worth $10,580,000 were sold in 1945, for an average of 170,000 per state. Average revenue from sales per state was $220,000. The price of a resident license ran from 50 cents to $3.55. These figures are probably changing rapidly, as it is known that several states are at present raising their license fees to take

TABLE 3.—*A summary of pond-fish-management problems and policies reported by state fishery administrations*

[Where no entry was made a reply was not received. States ommitted that sent no information on points listed]

State	Pondfish cultured (thousands)	Advisable to stock pondfish in waters where species is already present	Have overpopulation problem	Chief attack on overpopulation	Principal pondfish management problem
Alabama	4,500	No	Yes	Restocking	Weeds; overpopulation
Arizona	400	No	Yes	Larger take	Weeds; overpopulation
Arkansas	—	Sometimes	No	Weed control	Cannibalism
California	130	No	Yes	Larger take	Overpopulation; species balance
Colorado	150	No	Yes	Larger take	Private lands
Connecticut	—	No	Yes	Larger take	Public relations
Delaware	3 ponds	—	—	—	—
Florida	4,000	Yes	No	—	—
Georgia	3,000	No	Yes	Removal	—
Idaho	20	Yes	Yes	Larger take	Population control
Illinois	12,000	No	Yes	Removal	Overpopulation
Indiana	10,000	Yes	Yes	—	Short growing season
Iowa	—	Sometimes	Yes	Removal	—
Kansas	—	No	Yes	Removal	—
Kentucky	156	Sometimes	Yes	Corrections	Species balance
Maine	—	—	Yes	Removal	—
Maryland	800	Bass, yes	Yes	Removal	Weeds; muskrats
Massachusetts	1,000	No	Yes	Removal	Production of fish
Michigan	—[1]	No	—	—	—
Minnesota	771,000	No	Yes	Larger take	—
Mississippi	—	Yes	No	Larger take	—
Missouri	—	—	Yes	—	—
Montana	—	No	Yes	Larger take	—
Nebraska	1,300	No	Yes	Removal	—
New Hampshire	—	Doubtful	Some	Larger take	Food supply
New Mexico	—	Yes	Yes	Larger take	—
New York	8,450	Yes	Yes	Salvage	Temperatures
North Carolina	—	—	—	—	Lack stock for new ponds
North Dakota	400	Yes	Yes	Removal	Water depth
Ohio	4,500	No	Yes	Larger take	Lack information
Oklahoma	2,600	No ?	Yes	Larger take	Need more management
Oregon	—	No	Yes	Poisoning	Overpopulation
Pennsylvania	1,000	Doubtful	Yes	Better Management	Space
Tennessee	80	Doubtful	Yes	Removal	Population balance
Texas	22,000	[2]—	Yes	Removal	—
Washington	—	No	Yes	Poisoning	Overpopulation
West Virginia	1,100	No	Yes	Poisoning	—
Wisconsin	2,000	Varies	Yes	Larger take	Lack brood stock
Wyoming	—	No	Yes	Larger take	Winter-kill

[1] Discontinuing

[2] Experimenting

[The symbol (–) indicates no reply was received. States omitted that sent no information on points listed]

State	Annual fishing license sales (thousands)	License cost, resident and non-resident (dollars and cents)	Intensive management program for state waters	Number of fishery administrators	Number of fishery biologists	Number of employees in trout culture	Number of employees in pond-fish culture	Other fishery employees
Alabama	50	1.00– 5.00	Yes	–	–	–	25	–
Arizona	44	1.75– 3.50	No	1	1	17	2	–
Arkansas	250	1.50	Not yet	2	1	0	15	5
California	550	2.00– 3.00	Yes	9	13	120	5	–
Colorado	196	2.00– 3.00	Yes	2	8	75–100	4	–
Connecticut	51	3.55	Yes	1	4	11	0	5
Delaware	3	1.25– 7.50	–	–	–	–	–	–
Florida	80	2.00– 7.50	Yes	–	–	–	–	–
Georgia	–	–	No	3	0	3	6	–
Idaho	100	2.00– 5.00	Yes	1	2	25	2	0
Illinois	–	1.00	Yes	1	4	0	10	22
Indiana	652	1.50	–	2	2	0	30	–
Iowa	250	1.00	Yes	1	5	2	6	30–100
Kansas	–	–	–	–	–	–	4	–
Kentucky	110	1.00	Yes	3	10	0	7	1
Maine	160	1.15– 5.15	Yes	2	3	55	0	3
Maryland	35	1.50– 5.50	Yes	2	2	4	4	0
Massachusetts	280	2.00	No	2	2	18	4–8	0
Michigan	–	–	Yes	5	50	82	24	40
Minnesota	750	1.00– 3.00	Yes	6	6	10	25	0
Mississippi	6	1.55	Yes	1	5	0	0	0
Missouri	–	1.15	Yes	–	4	15	–	–
Montana	115	2.00	No	1	0	30	0	0
Nebraska	130	1.00	Not yet	1	2	6	12	0
Nevada	20	1.50– 3.00	Not yet	0	0	3	5	0
New Hampshire	113	2.50– 4.00	Yes	1	2	40	–	15
New Mexico	40	2.00– 3.00	No	1	0	15	0	0
New York	–	–	Yes	15	12	–	–	–
North Carolina	50	3.10– 6.10	Yes	2	2	10	3	2
North Dakota	35	0.50	No	1	0	0	3	2
Ohio	600	0.50	Yes	4	22	0	7	–
Oklahoma	–	1.50	Yes	2	2	0	18	1
Oregon	140	3.00– 5.00	Yes	2	15	30	1	–
Pennsylvania	400	1.50– 2.50	Yes	[1]15	–	[2]76	–	66
Rhode Island	15	5.25	Yes	–	–	4	–	16
Tennessee	140	2.00	No	2	2	0	6	1
Texas	120	1.10	No	2	5	0	30	0
Utah	74	2.00	Yes	2	2	18	–	6
Vermont	48	1.25	No	2	3	15	0	2
Washington	300	3.00	Yes	2	10	49	0	0
West Virginia	215	2.00– 5.00	Yes	2	3	10	8	1
Wisconsin	260	1.00– 3.00	Yes	11	8	35	6	30
Wyoming	77	1.50–10.00	Yes	1	2	16	0	0

[1] Includes both administrators and biologists

[2] Includes both trout and pond-fish culturists

care of increased costs. The average license price in trout states was $1.75 and for non-trout states $1.28. It is probable that the cost of licenses will see the biggest continual rise in trout states, particularly in those with large programs in creel-sized fish, since few present individual license prices pay for one limit catch of hand-reared trout.

Of 40 states reporting on the status of intensive management of their fisheries, 29 indicated that they have such a program in operation, 3 said that they hope to have one soon, and 8 have no such program.

In the 35 states reporting on numbers of men employed in various lines of fisheries, a total of 98 men are in administrative posts for an average of 2.7 per state. New York has 15 administrators to top the list, followed by Wisconsin with 11, and California with 9. One state has no fishery administrator.

The same states report a total of 214 men in biological work, for an average of 6 biologists and assistants per state. Topping the list is Michigan with 50, followed by Ohio with 22, and Oregon with 15. Four states have no biologists and two have but one each.

The 26 states engaged in trout culture employ 741 men in this work for an average of 27 per state. California hires 120 trout culturists, followed by Colorado with 100 and Michigan with 82. The 26 states engaged in pond-fish culture have a total of 271 men in this work for an average of 10.8 per state. Topping this category are Illinois and Texas with 30 each, followed by Alabama and Minnesota with 25 each. Also employed were a total of 318 men in other lines of fishery work such as salvage crews, rough-fish-removal crews, and tenders of irrigation screens.

It is interesting to note that an average of 3.2 men were required for each trout hatchery, and the average state produced roughly 6,700 pounds of trout per hatchery employee. There seems to be considerable disparity among states in manpower efficiency. Of course larger plants should realize greater efficiency than smaller ones, but even among the larger producers we find a great divergence. For instance, in comparing two states, each of which produces over a million catchable trout yearly, we find one operating at a ratio of 31,000 pounds per employee, and the other at 3,500 pounds per man, or roughly nine times the manpower effort. Another state producing fish over the million mark rears 20,000 pounds per man, while yet another produces but 3,900 pounds per hatchery worker. The least efficient state produces but 1,400 pounds per man. The State of Utah leads in employee efficiency with 31,000 pounds per man, followed by Washington with 20,000 pounds and Iowa with 15,000. It is probable, however, that some of the larger states with considerable revenue have their manpower efficiency lowered by work not directly concerned with the rearing of trout, such as the maintenance of more attractive hatchery grounds.

RELATION OF DISSOLVED OXYGEN TO WINTER MORTALITY OF FISH IN MICHIGAN LAKES[1]

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Abstract

Winterkill of fish in southern Michigan lakes during 1944–45 provided an opportunity to study the effect of different degrees of oxygen depletion on the extent of mortality and survival of several common species of fishes. Eleven lakes were investigated. Several inches of snow cover remained on the lakes from December 11 to February 15. This abnormal persistence of snow cover was accompanied by oxygen depletion in some of the lakes to mid-winter lows occurring about February 14. The maximum concentration of oxygen in vertical series taken at about the time of greatest depletion ranged from 0.2 to above 5.0 p.p.m. in the different lakes. Where oxygen depletion was severe this maximum occurred only in a thin stratum immediately beneath the ice. Heavy winterkills occurred only in those lakes in which the dissolved oxygen was depleted to approximately 0.6 p.p.m. or less. The mortality was greatest among bluegills and largemouth bass, apparently 100 percent in some lakes. Among the pumpkinseeds, mud pickerel, northern pike, chub suckers, bullheads, and golden shiners there was a large rate of survival even in lakes where the oxygen was reduced to 0.3 or 0.2 p.p.m. No complete kill of all fish in a lake was encountered.

Introduction

Winterkills of fish on an important scale occurred in many Michigan lakes during the winters of 1935–36, 1939–40, 1940–41, and 1944–45. The lakes involved are very shallow, with muck and peat bottom, and with abundant vegetation. Most winterkills in Michigan have occurred in lakes in the southern half of the Lower Peninsula. The reasons for this geographical distribution are not apparent, but may depend on a greater fertility of the more southerly lakes or a general geographical difference in the character of the cover of ice and snow.

The returns from a questionnaire sent to the Michigan conservation officers, together with our own observations, resulted in a tabulation of 51 lakes with a heavy kill in 1944–45; and judging from subsequent reports, the actual number probably exceeded 75. For the winters 1935–36, 1939–40, and 1940–41, Greenbank (1945; Fig. 2) plotted the distribution of the "most serious instances" of reported winterkills, recording 34, 12, and 11 lakes, respectively.

Presumably the true numbers of lakes which experienced important kills during these years were considerably greater. In the 1944–45 kill, with counts of dead fish on seven lakes used as a basis, the fish mortality in the 51 lakes was estimated at 2 million or more fish, of which approximately three-fourths were game fish.

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The present paper deals with events of the winterkill in 1944–45. The study was begun in January 1945, when it was suspected on the basis of prevailing weather conditions that a winterkill might take place. The field studies, conducted on numerous lakes, involved collection of the following data: (1) analyses of dissolved oxygen during January to March; (2) direct observations on mortality and survival and on behavior of fish at the time of reduced oxygen; (3) the kinds and numbers of dead fish that floated to shore at the time the lakes were cleared of ice in the spring; and (4) the kinds and relative abundance of surviving fish as determined by netting during 1945 and 1946. The present account is limited mostly to the results obtained on six lakes in which some mortality took place. Several other lakes in which little or no mortality occurred are cited for comparison. The aim of this paper is to describe the relationship between the degree of oxygen depletion and the extent of mortality and survival of the various species of fish in the several lakes.

The results of an intensive study of the limnological conditions related to winterkill in lakes of southern Michigan were the subject of a recent paper by Greenbank (1945). That author also summarized much of the literature on the subject.

Winterkills are not only confined to shallow, mud-bottom, weedy lakes, but occur generally only during winters when lakes are covered with cloudy ice and heavy snow for unusually long periods. Cloudy ice and snow greatly inhibit the penetration of sunlight into the lake water. Where such a condition prevails without interruption for several weeks on shallow and organically rich lakes, the loss of dissolved oxygen through organic decomposition exceeds the production of oxygen by photosynthesis to the extent that oxygen values are eventually reduced almost to the vanishing point. Winter oxygen profiles on rich lakes typically show much less oxygen in deep than in surface waters, and under conditions of extreme depletion the oxygen may be limited to mere traces in surface waters. Winterkills usually have been found associated with low dissolved oxygen. The majority opinion of various investigators has been that the fish die because of a lack of oxygen, although some have suggested that death might be due to the presence of "poisonous" gases such as hydrogen sulfide, methane, and carbon dioxide, which are usually prevalent under conditions of low oxygen. The question has not been settled by controlled experiments on the effect of each factor alone. Thus it is not certainly established whether the fish die because of lack of oxygen, because of the presence of harmful gases, or because of a combination of the two. However, the question is perhaps of limited importance to the present paper, in which the most significant contribution is information on the extent to which fish will survive at very low oxygen values.

METHODS

Sampling for determinations of dissolved oxygen was started on four lakes on January 12 and was continued at approximately weekly intervals to the first week in March. The seven additional lakes were sampled on one or two dates during the first part of February. In the four lakes that were sampled weekly, the extreme in oxygen depletion was reached immediately preceding the thaw which occurred on February 14–15. It may be assumed, therefore, that the samples from the other seven lakes in mid-February gave oxygen values which were near the winter minima.

Samples were taken at several stations on Green Lake, at two stations on First Sister, and at one station on each of the remaining lakes. The stations on Green Lake were at scattered points in both shallow and the deeper water and in an area near the inlet. On the other lakes the stations were near or over the deepest water and/or near the lake centers. Holes were spudded through the ice with as little agitation of the water as possible. Samples were taken from the surface (upper foot) and usually at the bottom and at intermediate depths, by means of the can type of sampler described by Greenbank (1945). Oxygen tests were made by the unmodified Winkler method.

Some observations were made on fish activity and mortality at sampling stations and at larger holes cut in the ice for this purpose. Examinations of the lake bottom for dead fish were aided by the use of a canvas covering over the observer. During late February observations were made on dead fish lying against the under surface of the ice in places where the ice was transparent. At Green Lake the concentration of live fish in the inlet during the time of greatest oxygen depletion in the lake was investigated.

On Green Lake it was observed that heavy mortality occurred during January and February, that large numbers of the dead fish were lying against the under surface of the ice during late February, and that these fish drifted to shore *en masse* when the lake was cleared of ice. A similar sequence of events was noted for dead fish on other lakes.

When the lakes cleared of ice about March 16, the presence or absence of dead fish along shore was noted, the fish were identified as to species, and counts were made of their numbers. The counts of fish along measured, representative sections of shore served as a basis for estimating total mortality. Our figures on total mortality are recognized as considerably below the true values, since it is believed that some of the dead fish do not come to the surface and also that many of the smaller ones disintegrate as a result of wave and ice action.

During the spring and summer of 1945 and 1946 the lakes which suffered a winterkill were netted (by fyke nets, gill nets, and seines) to determine the kinds and general abundance of the species that had survived.

The species of fish to which reference is made in this paper are as fol-

TABLE 1.—*Locations and some physical features of lakes considered in this report*

Lake	County	Township and range	Area (acres)	Maximum depth (feet)	Approximate average depth (feet)	Inlet and outlet
Cavanaugh.........	Washtenaw	2 S., 3 E.	217	20	6	None
Four Mile	do.	1 & 2 S., 4 E.	256	18	5	Both small
Mill................	do.	2 S., 3 E.	142	25	8	do.
Sugarloaf..........	do.	1 S., 3 E.	180	20	4	Inlet 100 g.p.m.[2], and springs, large outlet
Cassidy............	do.	1 S., 3 E.	46	12	4	No inlet, small outlet
Grass..............	Jackson	2 S., 2 E.	360	[1]10	[1]5	Both small
Batteese...........	do.	1 S., 1 E.	100	[1]16	[1]7	do.
First Sister........	Washtenaw	2 S., 5 E.	4	20	7	None
Goose..............	Jackson	2 S., 1 & 2 E.	425	[1]8	[1]3	Both small
Green..............	Washtenaw	1 S., 3 E.	90	11	4	Inlet 50 g.p.m.[2], dam at outlet
Merkle.............	Jackson	1 S., 2 E.	88	12	4	None

[1] Estimates based on casual observations; intensive surveys have not been made.
[2] Gallons per minute.

lows: largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), black crappie (*Pomoxis nigro-maculatus*), pumpkinseed (*Lepomis gibbosus*), warmouth (*Chaenobryttus coronarius*), mud pickerel (*Esox vermiculatus*), northern pike (*Esox lucius*), brown bullhead (*Ameiurus nebulosus*), yellow bullhead (*Ameiurus natalis*), black bullhead (*Ameiurus melas*), tadpole madtom (*Schilbeodes mollis*), lake chubsucker (*Erimyzon sucetta*), yellow perch (*Perca flavescens*), Iowa darter (*Poecilichthys exilis*), golden shiner (*Notemigonus crysoleucas*), blackchin shiner (*Notropis heterodon*), blacknose shiner (*Notropis heterolepis*), central mudminnow (*Umbra limi*), blackstripe topminnow (*Fundulus notatus*), brook silverside (*Labidesthes sicculus*), and bowfin (*Amia calva*).

Description of the Lakes

The lakes studied are located in the southeastern corner of the Lower Peninsula of Michigan, in Washtenaw and Jackson counties. Their names, locations, and some of their physical features are given in Table 1. The five lakes listed last are those in which extreme oxygen depletion was accompanied (except in First Sister) by heavy mortality of fish. The sizes of these lakes range from 4 acres to about 400 acres. Their maximum depths are mostly less than 20 feet, and their average depths about 3 to 7 feet. They have either very small inlets and outlets or none at all, and consequently there is no appreciable displacement of water during the winter. Rooted plants are abundant in most of them. In most features the six lakes that did not suffer heavy winterkill are closely similar to those that did have winterkill.

Time and Nature of the Snow and Ice Cover

These lakes were frozen over by early December 1944 and were blanketed by several inches of snow on December 11. They remained completely covered by snow almost continuously until February 15, 1945. The thickness of the snow cover, which was measured frequently from January 12 to February 14, varied from 2 to 5 inches and averaged about 3 inches. Additional snowfall on January 22 and February 7 compensated for occasional light thaws and packing. There was little rain or thaw water on the ice; thus the snow and ice remained dry throughout the period. The thickness of ice averaged approximately 6 inches on January 12, 10 inches on January 29, and 12 inches on February 12.

On February 14–15 there occurred a 24-hour thaw and a light rain which cleared most of the snow from the lakes. As a result the ice surface was covered with large amounts of water which poured into the lakes through fractures in the ice. This thaw initiated a period of oxygen rejuvenation in those lakes which up to February 14 were experiencing a considerable oxygen depletion. Subsequent thaws in late February and early March added more surface water to pour into the lakes. The lakes were clear of ice on March 16. February 14 marked the end of the downward trend in dissolved oxygen.

SEVERITY OF OXYGEN DEPLETION AND REACTIONS OF THE FISH

In the vertical series of oxygen samples at the various stations the surface samples (taken at a depth of from 6 inches to a foot below the surface) almost invariably had the most oxygen. In the following discussion only the surface oxygen values are cited in most instances.

Maximum oxygen values on Green Lake at two stations on January 12 were 2.2 and 4.7 p.p.m.; at the one station sampled on January 22, the maximum was 0.9 p.p.m.; at two stations on January 29, the highest values were 0.4 and 0.1 p.p.m.; at eight stations on January 31, oxygen in surface samples ranged from 0.05 to 0.8 p.p.m., and at seven stations on February 5 to 7, surface values ranged from 0.1 to 0.3 p.p.m.

The single inlet to Green Lake was about 150 yards long, and had a flow of about 50 gallons per minute; the current was mostly sluggish. This inlet served as a refuge for many fish while the dissolved oxygen in the lake was at a low point. On January 29 it contained an estimated 2 to 4 thousand fish, 3 to 8 inches long. Included were mud pickerel, bullheads, chubsuckers, golden shiners, pumpkinseeds, yellow perch, and mudminnows. No bluegills, crappies, or bass were seen, however, among hundreds of fish identified. On January 31 the number of fish "packed" into the inlet was estimated at 15,000. At the head of the inlet, above the 15,000 fish, the dissolved oxygen was 7.1, while at the mouth of the inlet it was 0.05 p.p.m. The estimated 10,000 fish, which had moved from the lake into the inlet between January 29 and 31, had been living in the lake during a period, probably of at least several days, when the oxygen was below 1 p.p.m.

On January 29, many dead fish were observed on the bottom of Green Lake through large holes cut in the ice. Oxygen in the lake had been below 1 p.p.m. for at least a week. Several live bluegills (adult and juveniles), bullheads, pumpkinseeds, and perch appeared in one of the openings on January 29. These fish apparently were distressed, but otherwise normal. The oxygen concentration was 0.4 p.p.m. at the surface in this opening. At one of the holes, reopened on January 31, five adult black crappies were observed; the surface oxygen was 0.8 p.p.m. On February 1, many bullheads and one golden shiner were observed in an opening where the surface oxygen was 0.8 p.p.m. On February 5, several dead bullheads and one live one were observed in a reopened hole where surface oxygen was 0.1 p.p.m.

The observations at Green Lake indicate that by the time dissolved oxygen had been reduced to less than 1 p.p.m. (quite uniformly over the lake and in the lower part of the inlet) there had been a considerable mortality of fish. However, many fish were still living in the lake, including some bluegills and black crappies and (those which subsequently moved into the inlet) many perch, mud pickerel, bullheads, pumpkinseeds, chubsuckers, and golden shiners.

In First Sister Lake, which is without inlet or outlet, dissolved oxygen at the two stations was down to less than 0.5 p.p.m. for at least a week in February. The surface values were 0.4 and 0.2 p.p.m. on February 5 and 0.2 and 0.3 p.p.m. on February 14. For the following 2 weeks the oxygen concentration was mostly less than 1 p.p.m. A wind-driven air pump had been installed at the lake, with the air vent near the lake bottom in about 8 feet of water. The upwelling of water caused by the release of air from this vent kept a 12-foot opening in the ice almost continuously. The air pump was not accomplishing its intended purpose—of maintaining a high oxygen concentration in the lake—but it provided an opening for frequent observations. One of the two sampling stations was at this hole above the air-pump vent. On January 12 and 29 surface oxygen values were 2.9, .3, and 1.1 p.p.m., and there was no concentration of fish at the air hole. On February 5, when the surface oxygen was 0.4 p.p.m. at the center of the lake and 0.2 p.p.m. at the air hole, live fish were observed at this opening. These fish included several young bluegills and chubsuckers, some hundreds of golden shiners, and several adult mud pickerel. The fish were distressed and were crowding near the surface, but they were sufficiently wary to be readily frightened away. On February 14 the surface oxygen was down to 0.2 and 0.07 p.p.m. at the two stations, and a sample secured by skimming the surface film at the air hole gave only 0.3 p.p.m. of oxygen. At this time there were an estimated 10 to 20 thousand fish milling around at the surface of the air hole. They were distressed, but still wary and easily frightened. The fish were mostly golden shiners and bullheads, plus a few chubsuckers, pumpkinseeds, black crappies, mud pickerel, and mudminnows, and one northern pike. About a dozen dead golden shiners and bullheads were at the surface. It is concluded that in this lake many thousands of fish, mostly golden shiners and bullheads, lived for at least a week at oxygen concentrations of less than 0.5 p.p.m.

On Batteese Lake the surface oxygen concentration was 7.8 p.p.m. on January 12, 1.6 p.p.m. on February 5, and 0.05 and 0.6 p.p.m. at two stations on February 13. Presumably the February 13 values represented the low point for the season. In a fish shanty near one of the stations on February 13, we observed about a dozen juvenile bluegills pass beneath us during a period of 10 minutes. Fishermen reported seeing no dead fish up to this date, but they had observed that fish were unusually near the surface.

On February 5 surface oxygen on Merkle Lake was 0.2 p.p.m. and on Goose Lake it was 0.5 p.p.m. No observations of mortality were made on these two lakes at the time of oxygen sampling.

At Grass Lake oxygen concentration at the surface was 0.7 p.p.m. on February 14 (presumably the low point for the season). On this date and near the sampling station live bluegills were observed beneath thin ice in a frozen-over fishing hole. On February 27 transparent ice provided a good opportunity to observe any dead fish lying against the under surface of the ice. Only a few dozen centrachids and perch were seen, from which it was concluded that the kill was light.

On Sugarloaf Lake oxygen values at the one station were :5.4 p.p.m. on January 12; 7.9 p.p.m. on January 22; 4.4 p.p.m. on January 29; 2.6 p.p.m. on February 5; and 1.8 p.p.m. on February 12. On February 19, the values were 1.8 p.p.m. at a depth of 3 inches and 0.7 p.p.m. at a depth of from 6 inches to a foot. The latter figures presumably represent the minimum for the winter. In early March a very few dead fish were seen through the ice. Several fishermen reported seeing no distressed fish around their fishing holes.

Oxygen samples on Cassidy Lake were taken only on February 19, four days after the thaw on February 15. The surface oxygen was 1.1 p.p.m., and judging from the observed oxygen changes on other lakes during this period, it is probably that this figure for Cassidy Lake was not much above the winter low. The surface oxygen value for Mill Lake on February 12 was 4.1 p.p.m., for Cavanaugh Lake on February 14 it was 9.2 p.p.m. and for Four Mile Lake on February 16 it was 7.4 p.p.m. The probable winter minima of oxygen values for these three lakes were about 4, 9, and not below 5 p.p.m., respectively. Accordingly no mortality was anticipated on these three lakes.

EXTENT OF THE WINTERKILL IN THE VARIOUS LAKES

At the time the ice went out in March, no significant numbers of dead fish were observed along the shores of Cavanaugh, Four Mile, Mill, Sugarloaf, Cassidy, and Grass Lakes. It was concluded that these lakes had no kill at all or else sustained only a very light one. No dead fish were observed at First Sister Lake; and it is considered unlikely that any heavy mortality took place.

On Batteese, Goose, Green, and Merkle Lakes the windrowed dead fish were estimated to number 330,000. This figure represented an average of several hundred fish per acre. The fish were mostly half-grown and adult; there were relatively few yearlings. The bluegill predominated among the dead fish. Pumpkinseeds, bullheads, largemouth bass, chubsuckers, yellow perch, and northern pike were the other principal species represented. Subsequent netting in these four lakes has shown that, of the largemouth bass and bluegills, a fair number survived in Batteese Lake, a few in Goose Lake, and apparently none in Green and Merkle Lakes. Among the yellow perch, chubsuckers, and northern pike there was a considerable mortality, but nevertheless a notably higher survival than for bass and bluegills. Bullheads and golden shiners had the best survival. The selectivity of the kill by species was against the interests of fishermen since the more desirable game species suffered the heaviest mortalities, and the least wanted kinds had the highest rate of survival. The same type of selective winterkill was noted by Eddy and Surber (1943), presumably for lakes in Minnesota.

Examination of the records of mortality and survival of fish in rela-

TABLE 2.—*Relationship between the severity of depletion of dissolved oxygen and the mortality and survival of fish in 11 lakes of southeastern Michigan*

Lake	Approximate minimum concentration (p.p.m.) of dissolved oxygen in upper 1 to 4 feet of water	Extent of mortality and survival
Cavanaugh	9.2 to 2.6	No kill
Four Mile	7.4 to 2.6 (probably not below 5.0)	do.
Mill	4.1 to 3.0	do.
Sugarloaf	1.8 to 0.7	Practically no kill; largemouth bass, bluegills, and other species present.
Cassidy	1.1 to 0.7 (probably not below 1.0)	Light kill, if any. Some kill reported; none observed. Largemouth bass, bluegills, and other species present.
Grass	0.7 to 0.6	Very light kill of largemouth bass and bluegills. No kill of other species.
Batteese	0.6 to 0.5	Heavy kill of bluegills; light kill of other species. Fair survival of largemouth bass and bluegills; good survival of perch, black crappies, golden shiners, brown and yellow bullheads, northern pike, pumpkinseeds, mud pickerel, blackstripe top minnow, and brook silverside.
First Sister	0.3 to 0.2	Extent of mortality uncertain. Good survival of golden shiners and bullheads.
Goose	0.5 to 0.05	Heavy kill of bluegills and largemouth bass; light kill of other species. Some survival of largemouth bass and bluegills; good survival of perch, chubsuckers, brown and yellow bullheads, golden shiners, mud pickeral, and bowfin.
Green	0.3 to 0.1	Very heavy kill of largemouth bass, bluegills, pumpkinseeds, perch, and black crappies; lighter kill of other species. Apparently no survival of largemouth bass and bluegills; good survival of perch, chubsuckers, yellow bullheads, golden shiners, blacknose shiners, and mud pickerel; some survival of black crappies and pumpkinseeds.
Merkle	0.2 to 0.0	Very heavy kill of bluegills, chubsuckers, largemouth bass, black crappies, pumpkinseeds, warmouth, northern pike, bullheads and perch. Some survival of brown and yellow bullheads, golden shiners, bowfin, blacknose and blackchin shiners, tadpole madtom, and Iowa darter. Apparently no survival of bass or bluegills.

tion to minimum winter oxygen values for the several lakes (Table 2) leads to the conclusion that a heavy mortality among the warm-water lake fishes, at near-freezing water temperatures, occurred only in lakes where the dissolved oxygen was depleted to considerably less than 1 p.p.m. The critical point for some species seemed to be in the range of 0.5 to 0.7 p.p.m. Among other species it was near 0.3 p.p.m. or even less.

The validity of these conclusions rests on the assumption that the minimum oxygen values obtained at single stations on most of the lakes were close approximations of the maximum amount of oxygen available throughout each lake. It is recognized that some variation in oxygen concentration does occur over the lake surface, and that inlets and flow from springs complicate matters by creating local areas of higher-than-average oxygen concentrations. The effect of an inlet carrying oxygen-rich water is illustrated by the concentration of fish, described above, in the stream flowing into Green Lake. On the other hand, the fact that every one of 13 scattered stations on this same lake gave oxygen determinations of less than 0.8 p.p.m. offers strong argument for a high degree of reliability for information secured at a single station. Furthermore, Green was the only lake in which fish were observed by us or reported by fishermen to concentrate in an inlet or outlet. The fact that dead fish lying against the ice were not found to be concentrated supports the interpretation that surface oxygen conditions were relatively uniform throughout each lake.

The toleration threshold of dissolved oxygen for largemouth bass and bluegills was about 0.6 p.p.m. For yellow perch, mud pickerel, pumpkinseeds, northern pike, and chubsuckers the toleration level, approximately 0.4 to 0.3 p.p.m., was definitely lower. Bullheads and golden shiners survived in still lower oxygen concentrations—at less than 0.3 or 0.2 p.p.m. Some of the smaller forage fishes, specifically blacknose and blackchin shiners and Iowa darters, survived in one lake which had less than 0.2 p.p.m. of oxygen. Even with such low oxygen values of 0.3 and less, no complete fish kill was encountered.

That certain species of fish will tolerate lower concentrations of oxygen at near-freezing temperatures than will others has been demonstrated experimentally by Moore (1942) and mentioned by Wilding (1939), Greenbank (1945), and others (references cited by Wilding and by Greenbank). Moore determined oxygen thresholds as follows: largemouth bass and northern pike, about 2.3 p.p.m.; yellow perch, 1.5; black crappie, 1.4; pumpkinseed sunfish, 0.9; bluegill, 0.8; black bullhead, 0.3; and golden shiner, 0.0. The thresholds as indicated by the present study are notably lower than Moore's figures, especially for largemouth bass, northern pike, yellow perch, and black crappie.

Acknowledgments

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Division in Lansing assisted in the winter oxygen sampling, and supervised and assisted in some of the counts of dead fish and in the subsequent netting to determine survival. Their cooperation has been appreciated.

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THE VITAMIN B REQUIREMENT OF TROUT

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Abstract

Brook, brown, and rainbow trout were fed diets containing various levels of thiamin, pantothenic acid, and riboflavin. After a period trout were killed and their livers analyzed for the vitamin content. The diet causing maximum storage was considered to be the tentative requirement of the trout. No difference was found between the requirement of three species of trout and no difference was found between the two temperatures at which the experiment was run. The tentative requirement for riboflavin was established at between 0.44 and 0.68, pantothenic acid between 0.97 and 1.25, and thiamin between 0.150 and 0.186 milligrams per kilogram of body weight per day. The maximum storage was found to be between 18 and 20 micrograms of pantothenic acid, 15 and 16 micrograms of riboflavin, and 3.5 and 4.5 micrograms of thiamin per gram of liver tissue. A difference was found between the two series with respect to the level of stored pantothenic acid and thiamin. This difference may be a function of age or size. The limitations of this type of study are discussed.

Introduction

Information on the vitamin requirements of trout is becoming increasingly important because scarcity of the usual hatchery foods necessitates the feeding of poorer quality diets. The Cortland Laboratory has therefore devoted the major portion of its summer program to this study from 1944 to 1946.

There have been relatively few studies on this subject because vitamin deficiencies in fish have only recently been recognized. Most previous work has consisted of trial-and-error experiments based upon rate of growth and degree of mortality. Such studies are subject to great variations and it is difficult to measure the rate of growth with the necessary precision. A definite need for specific vitamins has been shown in only a few cases. Wolf (1942), Tunison *et al.* (1942), and Woodbury (1943) have all shown that thiamin is essential in the diet of trout. Wolf (1943, 1945) and Tunison *et al.* (1944) reported that pantothenic acid was necessary for the prevention of a certain type of gill diseases. Simmons and Norris (1941) found that xanthopterin cured a type of anemia found in salmon. Davis (1927) and Gutsell (1939) both have shown that trout responded favorably when cod liver oil was included in their diet. Tunison *et al.* (1943) reported that a mixture of panothenic acid, riboflavin, and pyridoxine prevented the usual anemia which developed when trout were fed a synthetic diet. They were unable to repeat this work (Tunison *et al.*, 1944) but did show that anemic fish had a low storage of these three vitamins in their livers. Phillips *et al.* (1940) reported that trout responded directly to the amount of vitamin A in their diet as reflected by the vitamin A content of their livers. Only beef liver was a suitable source of this vitamin since neither cod liver oil nor carotene had any effect. This difference was probably due to varying forms of vitamin A in different foods.

Many of the B-complex vitamins are stored in the body to a limited extent, regardless of excesses in the diet. It is therefore possible to determine the amount of dietary vitamin needed to cause maximum storage in some organ, such as the liver. Tunison *et al.* (1944), Phillips and Tunison (1947), and Phillips *et al.* (1945) have used this rather indirect method in preliminary experiments with trout. From their data they arrived at tentative requirements of trout for pantothenic acid, riboflavin, and pyridoxine. The present paper concerns similar experiments with three of the B vitamins— thiamin, riboflavin, and pantothenic acid—in which the measurement of several variables was made. Experiments were designed so that the effect of the level of the vitamin in the diet, the species of fish, water temperature, and time of analysis (age and fish size) could be ascertained.

Appreciation is expressed to Dr. C. M. Mottley whose help in the statistical procedures and in the preparation of the figures is gratefully acknowledged. Appreciation is also expressed to Donald R. Brockway, Martin W. Sullivan, and William Hassler for their help throughout the studies.

METHODS

Diets containing various amounts of each vitamin under consideration were fed to brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdnerii irideus*) from the start of the experiments in mid-April to their conclusion in early October. The fish were held in two series of troughs, one supplied with water at a temperature of 47°F. and the other at a temperature of 52°F. Unfortunately, the water supply did not permit these two lots to be held in the same hatchery and it was necessary to conduct the experiments in two separate buildings.

The method of handling the experimental fish was similar to the established procedure of the Cortland Hatchery (Tunison *et al.*, 1939).

Trout were killed and their livers analyzed for the vitamin content at approximately bimonthly intervals during the experimental period. The amount of vitamin in the diet which caused maximum storage in the liver at the time of analysis was taken as the tentative requirement of the trout.

Micro-biological assays were used for all three vitamins to make estimates of the vitamin content of the fish livers. The *Lactobacillus casei* method of Landy and Dicken (1942) was employed for determinations of both riboflavin and pantothenic acid. Trout livers were prepared

TABLE 1.—*Percentage composition of the diets together with the vitamin content of the diets and the amounts fed to the fish*

Diet	Hog melts percentage	Beef liver percentage	Salt percentage	Pantothenic Acid		Riboflavin		Thiamin	
				Micrograms per gram of diet	Milligrams fed per kilogram of fish[1]	Micrograms per gram of diet	Milligrams fed per kilogram of fish[1]	Micrograms per gram of diet	Milligrams fed per kilogram of fish[1]
1	98.0	....	2.0	16.2	0.98	7.4	0.44	2.3	0.138
2	86.0	12.0	2.0	20.8	1.25	11.4	0.68	2.5	0.150
3	58.0	40.0	2.0	31.6	1.90	20.4	1.22	3.1	0.186
4	....	98.0	2.0	55.3	3.32	40.5	2.40	4.2	0.252

[1] All fish fed 6 percent of their body weight as food per day.

for analyses according to the method of Neal and Strong (1943) for pantothenic acid and Strong and Carpenter (1942) for riboflavin. The thiamin assays were made according to the method of Hamner *et al.* (1943) using the fungus *Phycomyces blakesleeanus*.

Three determinations were made upon pooled liver samples from trout of each of the experimental troughs at the two time intervals (series) of the experiment.

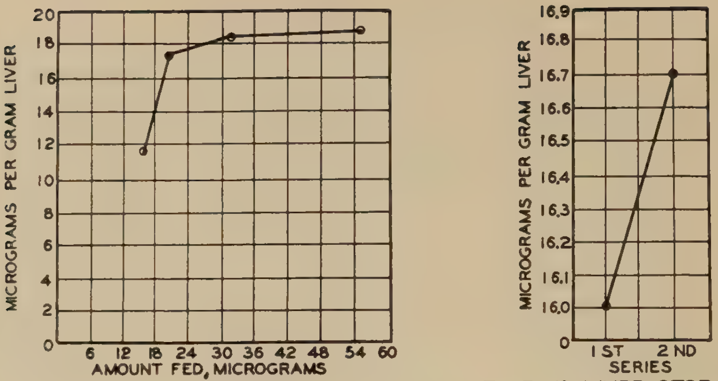
In order to regulate the amount of the vitamin entering the fish in terms of milligrams per kilogram of body weight, food was introduced in daily feedings at the rate of 6 percent of the body weight throughout the experimental period. In consequence the fish were slightly underfed during the early stages of the experiment and somewhat overfed during the later stages. Throughout the experiment all food offered to the fish was completely consumed.

Four diets consisting of varying percentages of hog melts, beef liver, and salt were used to provide different levels of available vitamins (Table 1).

All results were tested statistically by analysis of variance using a split-plot design.

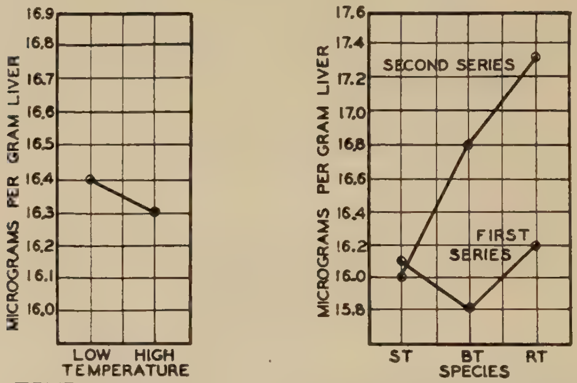
TABLE 2.—*Summary of the pantothenic acid experiments*

Diet number	Species of trout	First series		Second series	
		Average weight of fish (grams)	Micrograms of pantothenic acid per gram of fish liver	Average weight of fish (grams)	Micrograms of pantothenic acid per gram of fish liver
		Water temperature, 47°F.			
1	Brook	4.02	11.6	12.36	10.3
2	do.	5.09	17.0	15.42	17.3
3	do.	5.29	17.6	14.05	17.3
4	do.	4.81	18.3	13.64	18.3
1	Brown	2.01	12.0	4.56	12.3
2	do.	2.10	19.0	5.06	18.6
3	do.	2.02	17.6	4.98	18.0
4	do.	1.97	18.6	4.22	18.3
1	Rainbow	3.07	11.6	4.97	12.6
2	do.	3.66	16.3	5.82	17.6
3	do.	3.83	18.0	6.28	18.3
4	do.	3.20	17.6	4.45	19.0
		Water temperature, 52°F.			
1	Brook	4.47	11.6	14.35	11.3
2	do.	4.78	17.0	16.15	17.0
3	do.	5.08	17.3	15.71	18.0
4	do.	4.67	17.6	15.90	18.3
1	Brown	2.54	9.6	7.25	12.0
2	do.	2.14	14.6	6.50	16.0
3	do.	2.48	17.3	9.14	20.0
4	do.	2.24	18.0	6.80	19.6
1	Rainbow	4.27	12.6	10.42	13.3
2	do.	3.98	17.3	10.92	19.0
3	do.	4.60	17.6	11.70	19.6
4	do.	4.08	17.6	14.00	19.3



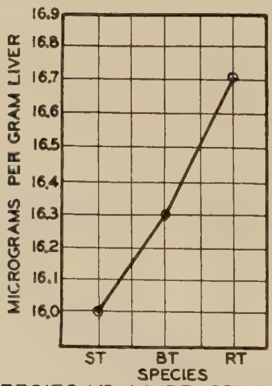
AMOUNT FED VS. LIVER STORAGE

TIME VS. LIVER STORAGE



TEMPERATURE VS. LIVER STORAGE

SPECIES VS. LIVER STORAGE THE TWO SERIES COMPARED



SPECIES VS. LIVER STORAGE

FIGURE 1.—Results of experiments with pantothenic acid. ST=brook trout; BT= brown trout; RT= rainbow trout.

THE PANTOTHENIC ACID REQUIREMENT OF TROUT

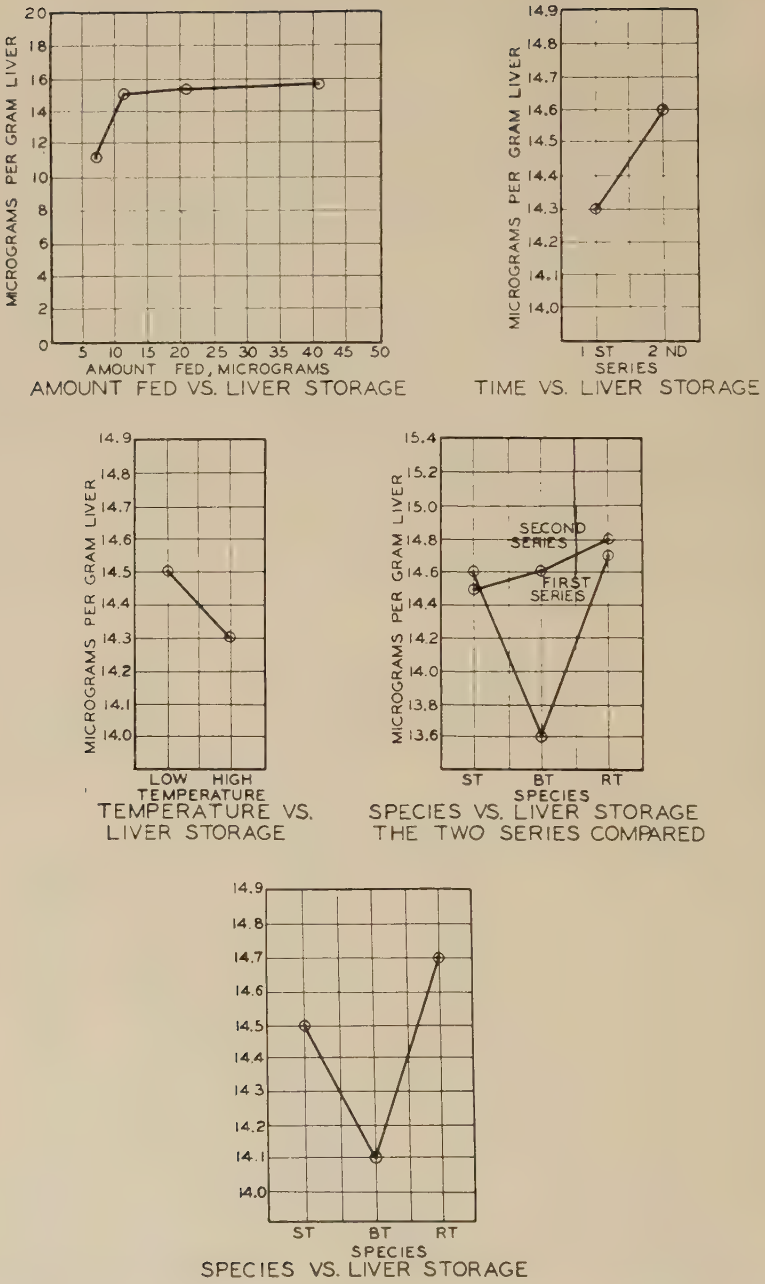
The amount of vitamin stored in the liver was dependent upon the amount present in the diet up to a maximum concentration (Table 2). Beyond this point additional vitamin in the diet had no effect. Maximum storage was found to be essentially the same for all three species of trout and averaged between 18 and 20 micrograms per gram of fish liver. These results are in agreement with those previously reported (Tunison *et al.*, 1944; Phillips and Tunison, 1947; Phillips *et al.*, 1945).

Since maximum storage in the liver was produced between the first and second levels of the diets (Diets 1 and 2), the daily requirement is concluded to be between 0.97 and 1.25 milligrams of pantothenic acid per kilogram of body weight per day. These results are also in agreement with those previously reported (Phillips *et al.*, 1945). There was no difference in the amount of vitamin necessary to cause maximum storage between the three species of trout.

There was no difference in the vitamin requirement of the trout held at 47°F. and those held at 52°F. Neither the increased metabolic rate of the fish nor the difference in the rate of growth altered the requirement at the higher temperature.

TABLE 3.—*Summary of the riboflavin experiments*

Diet number	Species of trout	First series		Second series	
		Average weight of fish (grams)	Micrograms of riboflavin per gram of liver	Average weight of fish (grams)	Micrograms of riboflavin per gram of liver
Water temperature, 47°F.					
1	Brook	2.81	12.3	8.30	11.3
2	do.	3.23	15.3	9.90	15.0
3	do.	3.34	15.0	10.21	15.6
4	do.	3.08	16.0	8.90	15.6
1	Brown	1.52	11.6	3.27	8.3
2	do.	1.52	15.0	3.43	16.6
3	do.	1.56	15.6	3.34	16.3
4	do.	1.53	15.0	3.06	16.6
1	Rainbow	2.56	12.3	4.16	12.0
2	do.	2.96	15.3	4.92	15.3
3	do.	3.03	15.0	5.20	16.3
4	do.	2.66	15.3	4.82	16.3
Water temperature, 52°F.					
1	Brook	2.86	11.3	9.22	11.6
2	do.	1.80	15.6	10.64	15.6
3	do.	2.29	15.3	12.06	15.6
4	do.	2.21	15.6	8.90	15.3
1	Brown	1.71	10.3	4.72	12.0
2	do.	1.41	12.0	4.35	14.3
3	do.	1.62	14.3	4.69	15.6
4	do.	1.43	14.6	4.30	16.3
1	Rainbow	2.91	12.0	7.51	11.6
2	do.	2.73	15.3	7.49	15.3
3	do.	3.01	16.0	10.00	16.3
4	do.	2.68	16.0	7.65	15.3



AMOUNT FED VS. LIVER STORAGE

TIME VS. LIVER STORAGE

TEMPERATURE VS. LIVER STORAGE

SPECIES VS. LIVER STORAGE THE TWO SERIES COMPARED

SPECIES VS. LIVER STORAGE

FIGURE 2.—Results of experiments with riboflavin. ST = brook trout; BT = brown trout; RT = rainbow trout.

There was a significant difference between the vitamin content of the livers analyzed in the first and that of the livers in the second series. The second series of analyses showed a higher liver storage than the first. It is concluded that some unmeasured factor such as size or age caused this effect. The trout were much larger at the time of the second series of analyses.

The average values of the major variables have been plotted in Figure 1. The differences outlined above are graphically shown in this figure.

THE RIBOFLAVIN REQUIREMENT OF TROUT

The storage of riboflavin in the liver was dependent upon the concentration in the food up to a maximum beyond which additional amounts in the diet had no effect. Maximum storage was essentially the same for all three species of trout and varied between 15 and 16 micrograms per gram of trout liver (Table 3).

Maximum storage occurred when the food contained riboflavin in amounts intermediate betwen 0.44 and 0.68 milligram per kilogram of body weight per day. These results agree with those previously reported (Phillips *et al.,* 1945).

There was no difference in requirements between the two temperatures at which the experiment was run or between the two series of analyses (Table 3, Fig. 2).

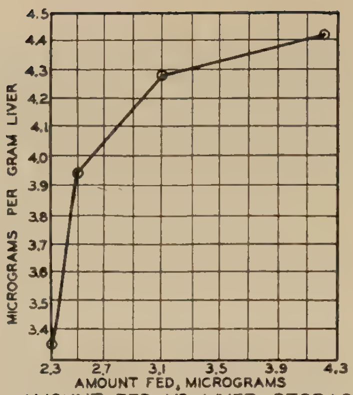
THE THIAMIN REQUIREMENT OF TROUT

As was found for the other two vitamins studied, the storage of thiamin in the livers increased with the availability in the diet to a maximum beyond which additional dietary thiamin had no effect (Table 4). Maximum storage was found to be between 3.5 and 4.5 micrograms of thiamin per gram of trout liver, with no significant difference between the three species of trout or the different temperatures at which the experiment was run. These data are at variance with those reported by Phillips *et al.* (1945) who found that brook trout required more thiamin as water temperature increased.

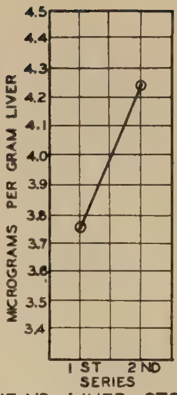
Maximum storage of thiamin in the trout livers was found when the diet contained between 0.150 and 0.186 milligram of thiamin per kilogram of body weight of trout.

There was a highly significant difference between the liver storage in the two series of analyses. The first or earlier series showed a lower average liver storage than the second or later series for all three species (Fig. 3). This variation may have been causd by size, age, or a combination of factors.

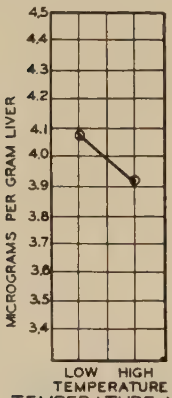
In view of these results, the difference between the author's experiments of 1945 and the present series in regards to temperature may be explained in a new light. The present series was subjected to a more rigorous statistical analysis than the previous experiments and more variables were taken into consideration. In the experiments of 1945 the



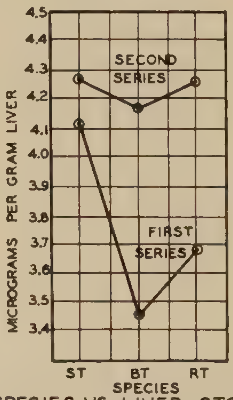
AMOUNT FED VS. LIVER STORAGE



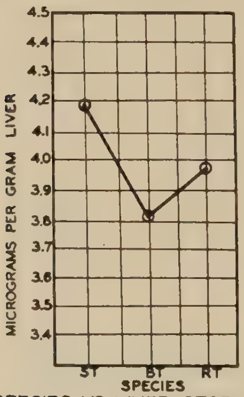
TIME VS. LIVER STORAGE



TEMPERATURE VS.
LIVER STORAGE



SPECIES VS. LIVER STORAGE
THE TWO SERIES COMPARED



SPECIES VS. LIVER STORAGE

Figure 3.—Results of experiments with thiamin. ST = brook trout; BT = brown trout; RT = rainbow trout.

TABLE 4.—*Summary of the thiamin experiments*

Diet number	Species of trout	First series		Second series	
		Average weight of fish (grams)	Micrograms of thiamin per gram of fish fish liver	Average weight of fish (grams)	Micrograms of thiamin per gram of fish fish liver
Water temperature, 47°F.					
1	Brook	8.35	3.6	15.97	3.6
2	do.	9.90	4.6	21.43	4.3
3	do.	10.21	4.4	19.80	4.5
4	do.	8.90	4.6	18.70	4.5
1	Brown	3.27	2.9	5.73	3.2
2	do.	3.43	3.1	6.72	4.4
3	do.	3.35	3.9	6.34	4.3
4	do.	3.06	4.2	5.10	4.6
1	Rainbow	4.16	3.3	5.45	3.6
2	do.	4.92	4.4	6.34	4.4
3	do.	5.20	4.2	7.20	4.4
4	do.	4.00	4.2	5.00	4.4
Water temperature, 52°F.					
1	Brook	7.24	3.3	15.25	3.5
2	do.	8.14	3.5	17.40	4.0
3	do.	9.09	4.4	21.40	4.8
4	do.	7.24	4.4	18.00	5.0
1	Brown	4.00	3.0	7.70	3.5
2	do.	3.49	3.1	7.00	4.1
3	do.	4.27	3.3	10.10	4.7
4	do.	3.42	3.9	6.98	4.7
1	Rainbow	6.23	2.9	11.00	3.7
2	do.	6.08	3.1	11.75	4.0
3	do.	7.03	3.7	12.90	4.6
4	do.	7.15	3.6	18.00	4.8

trout held at different temperatures varied considerably in size and there was an unavoidable delay in the analyses of the fish in the two sets of experimental troughs. It would appear, therefore, that the difference attributed to temperature in the 1945 series was caused by factors other than temperature. These factors might be age, fish size, or a combination of any number of variables not controlled in the present experiments. Such a possibility has been mentioned previously (Phillips *et al.*, 1945).

GENERAL DISCUSSION OF THE VITAMIN REQUIREMENT OF TROUT

The methods used in our studies for the determination of the vitamin requirements of trout have definite limitations. Maximum liver storage does not provide necessarily a true picture of the needs of trout and it is quite possible that the actual requirement is well below that estimated. Tentative requirements are therefore established with a wide margin of safety.

Changing the constituents of a diet to produce various concentrations of vitamins in the food is at best a poor method. There is no known synthetic diet that will satisfy the growth requirements since many unknown factors play important roles, especially in the control of anemia. The addition of synthetic crystalline vitamins to a basal diet is not satisfactory because undetermined quantities are lost in the water when the fish are fed. Further, since we do not recognize many deficiencies of vitamins in fish, it is not possible to conduct experiments on the amounts needed to prevent deficiency troubles. Recently it has been shown by several authors that there is an interdependence of many of the vitamins. Therefore, when diets are varied, any relationship between the vitamins is ignored and a chance for error is introduced. Likewise, the possibility that trout will utilize a vitamin from one source better than from another cannot be overlooked. In spite of the limitations of the foregoing studies, it is believed that they can establish a base for practical operation and further knowledge of vitamin requirements. As methods become more refined, greater accuracy and more knowledge of basic needs of trout can be acquired.

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EXPERIMENTS WITH COMBINATIONS OF LARGEMOUTH BLACK BASS, BLUEGILLS, AND MINNOWS IN PONDS

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Abstract

Various combinations of largemouth bass, bluegills, golden shiners, gizzard shad, and *Gambusia* were stocked in 0.25-acre experimental ponds. The ponds were fertilized with inorganic fertilizer. After 1 or 2 years the ponds were drained and the fish counted and weighed. The bluegill proved the most desirable forage fish, although it did not result in the highest bass production in these experiments. It appeared to offer promise of the highest sustained yield of bass over a period of years. Golden shiners gave higher bass production for a 1- to 2-year period, but could not maintain high production over a longer period. Goldfish could not be used with bluegills because the latter ate goldfish eggs and prevented reproduction. Goldfish also were not satisfactory when used with bass only, because many young grew too large for bass to eat and ate their own eggs, thus preventing further reproduction. Gizzard shad produced a high poundage of bass, but the young rapidly grew too large for bass to eat and overcrowded the ponds. As a result, they stopped reproducing and at the same time reduced bluegill production. *Gambusia* were unsatisfactory as forage fish because bass eliminated them almost entirely from ponds in a few months.

Introduction

In repeated experiments over a 10-year period with bluegills (*Lepomis macrochirus* Rafinesque and largemouth bass (*Micropterus salmoides* Lacépède) in fertilized ponds, a combination of these species has produced a combined annual catch of from 175 to 200 pounds of fish per acre. Of this total poundage the catch of bass has varied from 20 pounds to 61 pounds in different ponds receiving the same treatment.

The fertilization of ponds has resulted in increased catches of both largemouth bass and bluegills. For example, in one fertilized pond, the average catch over a 3-year period was 52.6 pounds of bass and 136.3 pounds of bluegills or a total of 188.9 pounds of fish per acre. In an unfertilized pond over the same period, the average catch was 22.8 pounds of bass and 17.3 pounds of bluegills or a total of 40.1 pounds per acre. Fertilization, therefore, increased the total catch of all fish by 320 percent. These data show further that the catch of bluegill was increased 688 percent, whereas the poundage of bass increased only 130 percent.

The principles underlying this differential increase caused by fertilization are relatively simple. Fertilization kills underwater weeds (Swingle and Smith, 1942), thereby reducing the cover for young bluegills. As a result, the largemouth bass are able to reduce the population of young fish to the extent that most of the weight of bluegills is in the form of large, desirable-sized fish. Such a condition produces excellent bluegill fishing, but cannot produce the best possible bass fishing.

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[1] Published with the approval of the Director

In fact, from the principles involved, it would not appear possible to produce the best possible bluegill fishing and the best possible largemouth bass fishing in the same pond. Good bluegill fishing requires a condition where most of the total weight of the bluegill population is composed of large fish, whereas high bass production requires a condition where most of the bluegills are small enough for bass to eat. Fertilization tends to produce the former condition. At the same time, however, it does increase bass production to a limited extent because the large bluegills produce heavy crops of young throughout the spring and summer months.

Bluegills spawn in central Alabama from the last of May to the first of October. Consequently young bluegills for bass food are scarce during the period from January to June. It would appear, therefore, that an earlier-spawning species which would furnish an abundant supply of young fish during this period would be of considerable value if added to a largemouth bass-bluegill combination. It would be necessary, however, that this additional species not compete with bluegills sufficiently to decrease their production materially.

The results of experiments with combinations of largemouth black bass and golden shiners (*Notemigonus crysoleucas* Rafinesque), gizzard shad (*Dorosoma cepedianum* LeSueur), goldfish (*Carassius auratus* L.), bluegills, and gambusia (*Gambusia affinis* Baird & Girard) are discussed in this paper.

METHODS

The desired combinations of species were stocked in 0.25-acre experimental ponds which were 2.5 feet deep at one end and sloped gradually to 6 feet deep at the other. All ponds were fertilized at the same rate with commercial 6–8–4 fertilizer and nitrate of soda or their equivalent (Swingle and Smith, 1942). The ponds were seined at regular intervals to determine spawning dates, relative abundance of minnows, and rate of growth of the largemouth bass. Types of food eaten by the forage fish were determined by stomach analyses. After 1 or 2 years, depending upon the experiment, the ponds were drained and the fish counted and weighed. A moderate rate of fertilization was used in order that the differences in the efficiency of the various forage fish for bass production might be more clearly determined.

GOLDEN SHINERS AS FORAGE FISH

Reproduction and food.—Golden shiners spawned at Auburn during the latter part of March and the first part of April. The first hatch was found April 8 with additional crops of young being produced at intervals throughout the summer until October 23. Although in this respect golden

TABLE 1.—*Production of fish in ponds stocked with largemouth bass fry in combination with goldfish, golden shiners, shad, and bluegills*

[Expressed in numbers and pounds per acre at time of drainage]

Stocked per acre[1]	Largemouth bass		Forage fish			Total pounds
	Number	Pounds	Species	Number	Pounds	
200 goldfish + 200 bass fry	172	52.0	Goldfish	1,808	275.0	327.0
200 golden shiners + 200 bass fry	128	74.0	Golden shiners	3,400	42.0	116.0
68 shad + 200 bass fry	164	106.0	Shad	48	83.6	189.6
200 bluegills + 200 bass fry	140	62.4	Bluegills	38,144	82.2	144.6
200 bluegills + 200 goldfish + 200 bass fry	[2]64	24.0	Goldfish Bluegills	51,996 4,280	572.0 18.0	614.0
200 bluegills + 200 golden shiners + 200 bass fry	172	94.0	Bluegills Golden shiners	12,730 236	62.0 2.0	158.0

[1] Goldfish stocked Nov 22, 1940, total weight 7.3 pounds per pond; golden shiners stocked Nov 22, 1940, total weight 1.7 pounds per pond; gizzard shad stocked Nov. 22, 1940, total weight 68 pounds per pond; bluegills stocked Nov. 15, 1940, total weight 4.1 pounds per pond; bass fry stocked May 8, 1941, total weight 1.2 ounce per pond. All ponds drained Nov. 27, 1941

[2] Only three bass large enough to eat goldfish

shiners are similar to bluegills, they produced heavy crops of young only during the spring.

Stomach analyses indicated that the golden shiners fed principally upon phytoplankton, microcrustacea, and aquatic Diptera. Consequently, they compete for food with bluegills to a considerable degree. Large shiners also fed to a slight extent upon small fish.

Golden shiners and largemouth bass fry.—In the first experiment (Table 1), 200 golden shiners per acre were stocked in November 1940 and 200 largemouth bass fry were added the following May.

The largemouth bass fry averaged 0.06 ounce each when stocked, 1.7 ounce by June 23, 3.6 ounces by July 21, 6.9 ounces by September 20, 8.6 ounces by October 18, and 9.2 ounces by November 27. Growth was slower after the middle of September, because the bass had seriously reduced the supply of minnows. When the pond was drained on November 27, 1941, it was supporting 74 pounds of bass and 42 pounds of golden shiners, or a total of 116 pounds of fish per acre.

Golden shiners and largemouth bass fingerlings.—In a similar experiment (Table 2) 200 golden shiners per acre were stocked in November 1940. In order to give these minnows a greater chance of survival, no bass were added until October 1, 1941, when 200 bass fingerlings were stocked. There were heavy hatches of minnows during the first summer, in May of the second year but no subsequent spawning. In March 1942, 28 bluegills entered the pond during a flood and reproduced during the summer. When the pond was drained on October 29, 1942, it was found to be supporting 118.0 pounds of largemouth bass, 38 pounds of shiners, and 58 pounds of bluegills, or a total of 214 pounds of fish per acre. Only 952 golden shiners were left at that time, while there were 3,868 bluegills, indicating that, had the experiment been continued, the bluegills would have been the main source of food for the bass during the next year.

Golden shiners, bluegills, and largemouth bass.—In the next experiment (Table 1) 200 golden shiners and 200 bluegills per acre were added November 22, 1940, and 200 largemouth bass fry the following May 8.

In this experiment, there was a heavy production of golden shiners in April and May. After these fish were reduced by the bass, there was a heavy spawning of bluegills in late July. Apparently large numbers of shiners retarded the early production of bluegills. On the other hand, the young bluegills apparently reduced the later spawning of golden shiners to the extent that only 236 were left when the pond was drained on November 27, 1941. At that time, there were present 94 pounds of largemouth bass, 62 pounds of bluegills, and only 2 pounds of golden shiners, or a total of 158 pounds of fish per acre.

In the next series of experiments (Table 3), golden shiners, largemouth bass fry and bluegills were again used, but the number of bluegills and bass was varied. In one pond, 100 golden shiners were added to the standard stocking rate of 1,500 bluegill fingerlings and 100 largemouth bass fry per acre; in a similarly stocked pond, the number of blugills

TABLE 2.—*Production of fish in ponds stocked with largemouth bass fingerlings in combination with golden shiners, and bluegills*

[Expressed in numbers and pounds per acre at time of drainage]

Stocked per acre[1]	Largemouth bass				Forage fish			Total pounds
	Size	Number	Pounds	Total pounds	Species	Number	Pounds	
200 goldfish + 200 bass fingerlings	Adult Young	148 840	140.0 29.2	169.2	Goldfish Golden shiner Bluegill	10,040 388 140	573.2 16.0 1.2	759.6
200 bluegill + 200 bass fingerlings	Adult Young	156 88	100.0 3.2	103.2	Bluegill	22,584	261.6	364.8
200 golden shiners + 200 bass fingerlings	Adult Young	156 228	100.8 17.2	118.0	Golden shiner Bluegill	952 3,868	38.0 58.0	214.0
200 goldfish + 200 bluegills + 200 bass fingerlings	Adult Young	156 0	43.2 0.0	43.2	Goldfish Bluegill	1,820 9,760	405.6 104.4	553.2

[1] Goldfish stocked Nov 22, 1940, total weight 7.3 pounds per pond; golden shiners stocked Nov. 22, 1940, total weight 1.7 pounds per pond; bluegills stocked Nov. 18, 1940, total weight 4.1 pounds per pond; bass fingerlings stocked Oct. 1, 1941, total weight 1.2 ounce per pond. All ponds drained on Oct. 29, 1942.

TABLE 3.—*Production of fish in ponds stocked with bluegill, golden shiner, and largemouth bass combinations*

[Expressed as numbers and pounds per acre at time of drainage]

Stocked per acre[1]	Largemouth bass		Forage fish			Total pounds
	Number	Pounds	Species	Number	Pounds	
1,000 bluegills + 100 golden shiners + 100 bass fry	54	54.0	Bluegill Golden shiners	46,272 285	334.0 20.0	408.0
1,200 bluegills + 100 golden shiners + 100 bass fry	40	52.0	Bluegill Golden shiners	14,148 2,126	262.0 90.0	404.0
1,500 bluegills + 100 golden shiners + 100 bass fry	92	127.0	Bluegill Golden shiners	24,508 625	384.0 100.0	611.0
1,000 bluegills + 100 golden shiners + 200 bass fry	88	64.0	Bluegill Golden shiners	37,439 90	232.0 6.0	302.0

[1] Bluegills stocked Oct. 8, 1941, weight 8.8 pounds per 1,000; golden shiners stocked Oct. 1, 1941, weight 3.3 pounds per 100; bass fry stocked May, 1942, weight 0.072 pound per 100. Ponds drained Oct. 29 and Nov. 3, 1943

was reduced to 1,200 and in another to 1,000 per acre. A fourth pond was stocked with 1,000 bluegills, 100 golden shiners, and 200 largemouth bass fry per acre to determine if the addition of minnows would necessitate the use of a greater number of bass in stocking ponds. In these experiments, the blugills and shiners were stocked October 8, 1941, and the bass fry in May 1942.

In 1942, the golden shiners hatched heavily in all ponds during April, approximately a month before the bluegills spawned. There was no later hatch of shiners, except for a light hatch in July in the pond where 200 bass per acre were used. The bluegills spawned heavily throughout June, but the ponds became so heavily crowded with shiners and small bluegills that no more bluegills hatched until September.

In 1943, there was practically no hatch of golden shiners, and only one young shiner was found by seining. In the early spring, the bluegills were crowded by the preceding year's young and did not spawn until July. Thereafter they produced young at intervals till fall. Because fish were overcrowded in the spring, no young largemouth bass were produced.

When the ponds were drained on October 29, 1943, the golden shiners had practically disappeared in two of the ponds, and had become of minor importance in the other two. It was apparent that they would be unable to maintain their numbers in a largemouth bass-bluegill combination over a period of years, and that their presence caused an overcrowded condition during the first year. The highest production per acre of largemouth bass (127 pounds), of bluegills (384 pounds), and of total fish (611 pounds) was obtained with the stocking rate of 1,500 bluegills, 100 golden shiners, and 100 largemouth bass per acre.

The foregoing results were checked in a 2-acre fertilized pond that was stocked March 14, 1941, with 2,600 bluegills and 184 golden shiners, and on May 8 of the same year with 200 largemouth bass fry. The golden shiners hatched in large numbers in May, June, and October 1941, spawned lightly in May 1942, and disappeared entirely from the pond in subsequent years. However, they did cause an overcrowded condition in the pond in the fall of 1941 and the spring of 1942, thereby preventing the largemouth bass and bluegills from hatching, and necessitated restocking with bass.

In a 90-acre fertilized pond stocked at unknown rates with golden shiners, largemouth bass, and bluegills, the golden shiners were very abundant during the first 2 years, were a minor part of the population in the third, and disappeared almost entirely in subsequent years. Bluegills have adequately maintained their numbers in this lake over a 6-year period.

Usefulness of golden shiners.—Golden-shiner minnows used either alone or in combination with bluegills are apparently unable to maintain their numbers in fertilized ponds which are also stocked with largemouth black bass. It is possible that this is partly due to the lack of cover in such ponds. However, observations in old unfertilized, weed-filled ponds indicate that under those conditions, also, the golden shiner becomes a very minor part of a bass-shiner-bluegill population. The inability of the golden shiners to maintain themselves is apparently due to the low rate of reproduction during the summer months, and also to the great length of time they require to reach a size too large for bass to eat. These two factors result in a gradually decreasing number of brood minnows and their eventual disappearance or reduction to a very minor part of the population.

GIZZARD SHAD AS FORAGE FISH

Reproduction and food.—Gizzard shad spawned at Auburn the last part of April. Usually additional light broods were hatched in June and as late as August 20 but only the April-May hatch was of much importance as food for largemouth bass. Although stomach analyses indicated that plankton forms were the principal food items, the finely ground condition of stomach contents made accurate determinations difficult. Fragments of chitin and fish scales showed that insects and small fish were also used to an undetermined extent. If shad are present in large numbers, therefore, they may be expected to compete with bluegills to considerable extent.

Gizzard shad and largemouth bass fry.—In this experiment (Table 1) 68 shad were stocked per acre November 20, 1940, and 200 bass fry added the following May 8. The pond was drained November 27, 1941, when the bass were about 7 months old.

A heavy hatch of gizzard shad was produced April 30 and light hatches on June 23 and August 20. Bass grew rapidly up to September 18, when they had an average weight of 10.6 ounces. By this time most of the small shad had been eaten so that when the pond was drained in November, the average weight of the bass was 10.3 ounces, or 0.3 ounce less than 2 months before.

Young shad grew rapidly during the late summer. Their average weight in August was 0.05 ounce and when the pond was drained in November the smallest weighed 3.7 ounces.

The pond produced 106.0 pounds of largemouth bass and 83.6 pounds of gizzard shad or a total of 189.6 pounds of fish per acre. A total of 48 shad remained, all too large for the bass to eat.

Gizzard shad, bluegills, and largemouth bass fry.—In this experiment (Table 4), a pond was stocked with 1,000 bluegills and 48 shad per acre in October 1941, and 200 bass fry per acre were added the following May. The pond was drained in November 1943. In 1942 gizzard shad began to hatch in the middle of March and continued into July. The first bluegills hatched in early May and spawning occurred at intervals the rest of the season. No shad hatched in 1943 but bluegills spawned lightly from July until fall.

Largemouth bass grew rapidly, reaching a size of 7 ounces by August 8, 1942. At that time the young gizzard shad were still small enough

TABLE 4.—*Production of fish in ponds stocked with bluegill, largemouth bass, and gizzard shad combinations*

[Expressed in numbers and pounds per acre at time of drainage]

Years	Stocked per acre	Largemouth bass				Forage fish			Total pounds
		Size	Number	Pounds	Total pounds	Species	Number	Pounds	
1942-43	1,000 bluegills + 48 shad + 200 bass fry[1]	Adult	136	101.0	101.0	Bluegill Shad	17,120 2,360	173.0 516.0	790.0
1944-45	1,500 bluegills + 200 shad + 148 bass fry[2]	Adult Young	44 48	76.0 1.0	77.0	Bluegill Shad	4,404 6,136	290.0 396.0	763.0
1943-44	1,500 bluegills + 150 bass fry[3]	Adult Young	92 16	40.0 2.0	42.0	Bluegill	30,073	261.4	303.4

[1] Bluegill stocked Oct. 8, 1941, total weight 8.8 pounds; shad stocked Oct. 1, 1941, total weight 13.8 pounds; bass fry stocked May, 1942, total weight 0.07 pound; pond drained Nov. 3, 1943

[2] Shad stocked Nov. 15, 1943, total weight 56 pounds; bluegills stocked Nov. 15, 1943, total weight 9.3 pounds; bass fry stocked May 17, 1944, total weight 0.03 pound; pond drained Nov., 1945

[3] Bluegills stocked Oct. 21, 1942, total weight 3.3 pounds; bass fry stocked May 10, 1943, total weight 0.108 pound; pond drained Nov. 7, 1944

to be eaten by the bass. In 1943, the shad reached a size of 1.5 to 2 ounces by the middle of the summer, and when the pond was drained in November, there were 516 pounds of gizzard shad per acre, the smallest being too large for the largest bass to eat.

This combination produced 101 pounds of largemouth bass, 173 pounds of bluegills, and 516 pounds of gizzard shad, or a total of 790 pounds of fish per acre. Of this total weight, 65.3 percent was shad, 12.7 percent bass, 13.5 percent adult bluegills and 8.5 percent young bluegills.

In a second experiment, (Table 4), 1,500 bluegills and 200 gizzard shad were stocked per acre on November 15, 1943, and 148 largemouth bass fry added May 17, 1944. The pond was drained in November 1945. It produced 77 pounds of largemouth bass, 290 pounds of bluegills, and 396 pounds of gizzard shad, or a total of 763 pounds of fish per acre. Of the total, 51.9 percent was shad, 10.1 percent bass, 26.7 percent adult bluegills, and 11.2 percent young bluegills. Of the 396 pounds of shad, all were too large for bass to eat.

Usefulness of gizzard shad.—Although gizzard shad produced a relatively high poundage of largemouth bass in a shad-bass combination, the yield of bass was not sufficiently large to justify omission of bluegills in ponds. Combinations of bluegills-shad-bass did not appear promising because large shad accumulated in the ponds and reduced the size of the adult bluegills. In comparable experiments, the average size of adult bluegills was 4.3 ounces in a bass-bluegill combination and 2.8 and 2.2 ounces respectively in two bass-shad-bluegill ponds. During the second year, gizzard shad reproduced only sparingly or not at all, apparently due to overcrowding by large shad, bluegills, or both. Experiments are now in progress upon the effects of periodic reduction of large shad in bass-shad-bluegill populations. It is possible that such removal may prove beneficial and may result in larger yearly crops of young shad.

GOLDFISH AS FORAGE MINNOWS

Reproduction and food.—Goldfish may spawn in late February at Auburn, but usually the first eggs hatch in March or April. Normally, only one crop of young goldfish was produced each year because the first brood, when one week old or older, ate subsequently laid eggs and newly hatched fish. When the first eggs were laid early enough that part were killed by cold weather, there was a light hatch and the young became relatively large in a few months. On the other hand, when the first eggs were laid during a warmer period, a heavy hatch resulted and the young remained relatively small. If adult fish were crowded they produced no young, but if they were given sufficient space, they reproduced heavily. Goldfish fed largely on plankton, but also took insects and very small fish in competition with bluegills.

Goldfish and largemouth bass fry.—In the first experiment (Table 1) 200 adult goldfish were stocked per acre in November 1940 and 200 largemouth bass fry added the following May 8. The pond was drained November 27, 1941.

Goldfish spawned heavily during March and April, producing a large crop of fish small enough for the young bass to eat when they were added in May. The young bass grew rapidly, averaging 6.9 ounces on August 20. The goldfish were then depleted so severely that the survivors rapidly became too large for bass to eat and their presence prevented the production of subsequent crops of young goldfish. Consequently, the bass lost weight, averaging only 5.5 ounces when the pond was drained. This combination produced 52 pounds of largemouth bass and 275 pounds of goldfish, or a total of 327 pounds of fish per acre. The remaining goldfish were all too large for the largest bass to eat.

Goldfish and largemouth bass fingerlings.—In this experiment (Table 2) 200 adult goldfish per acre were stocked November 22, 1940, and 200 largemouth bass fingerlings were added on October 1, 1941. The young goldfish were thereby allowed to attain a considerably larger size before they were fed upon by the bass. In fact, most of the goldfish were too large for the bass fingerlings, and the bass grew slowly at first. They averaged only 0.75 ounce in June 1942, 1.8 ounces in July, 4.3 ounces in August, and 0.95 pound in November when the pond was drained. The goldfish did not spawn during 1942 and the number of young of the previous year was so reduced that most of the survivors rapidly became too large for bass to eat.

When it was drained in October, 1942, a little more than one year after the bass were added as fingerlings, the pond was supporting 169.2 pounds of largemouth bass, 573.2 pounds of goldfish, 16 pounds of golden shiners, and 1.2 pounds of bluegills, or a total of 759.6 pounds of fish per acre. The golden shiners and bluegills accidentally gained entrance to the pond during the summer of 1942. At the end of the experiment, 10,040 goldfish per acre were present but the majority of them were too large for the bass to eat. Their numbers were so great that spawning of goldfish would have been prevented in succeeding years.

Goldfish, bluegills, and largemouth bass fry.—In this experiment (Table 1) 200 adult goldfish and 200 bluegills fingerlings per acre were stocked in November 1940 and 200 largemouth bass fry were added the following May 8. The pond was drained in November 1941 when the bass were approximately 7 months old. Goldfish hatched early in April and rapidly attained a size difficult for the bass to eat. Their large numbers greatly reduced the food for bluegills and resulted in a light egg production when the latter species began to spawn in July.

When the pond was drained in November, it was carrying fish at a rate of 24 pounds of largemouth bass, 572 pounds of goldfish, and 18 pounds of bluegills, or a total of 614 pounds of fish per acre. Unfortunately, only three bass had been able to grow large enough to eat any of the goldfish. Especially significant was the small yield of bluegills which definitely indicated that the large numbers of goldfish were detrimental to bluegill reproduction.

Goldfish, bluegills, and largemouth bass fingerlings.—In this experiment (Table 2) 200 goldfish and 200 bluegills were stocked in November 1940 and 200 largemouth bass fingerlings added October 1, 1941. Since very few goldfish were produced by the early hatch, bluegills were able to reproduce throughout the summer. When the pond was drained on October 1, 1942, it was supporting 43.2 pounds of largemouth bass, 405.6 pounds of goldfish, and 104.4 pounds of bluegills or a total of 553.2 pounds per acre. The 1,820 goldfish which averaged 3.6 ounces each greatly reduced the weight of bluegills in the pond.

Other goldfish-bluegill-largemouth bass combinations.—One pond was stocked with 48 goldfish, 1,000 bluegills, and 100 largemouth bass fry; a second with 48 goldfish, 1,500 bluegills, and 100 bass fry; and a third with 48 goldfish, 1,000 bluegills, and 200 bass fry per acre. The bluegills and goldfish were stocked October 1941 and the bass fry the following May 1942.

Goldfish were observed laying eggs in the early spring, but bluegills were also observed eating the eggs as they were deposited. The result was that no young goldfish were produced in any of these ponds. In two ponds all of the brood goldfish died during the latter part of the summer. In the third pond all lived, but produced no young. Conseqently, the ponds were all drained on October 29, 1942.

In another experiment a 1.8-acre pond was stocked with 10 white crappie (*Pomoxis annularis* Rafinesque), 10 yellow bullheads (*Ameiurus natalis* Le Sueur), 10 bluegills, 10 largemouth bass, and 89 goldfish of bait size in December 1936. Since the goldfish were too small to spawn before the bluegills and crappie, the pond contained 3,856 white crappie, 678 yellow bullheads, 20,704 bluegills, 4 bass, and only 3 large goldfish when it was drained in November, 1937. All these fish were returned and 89 more goldfish added. A year later the pond was drained and at that time only 2 goldfish, averaging 1.4 pounds, remained out of the total of 92 that were stocked. At no time during the summer could young goldfish be found in the pond.

In numerous other experiments it has been found that when goldfish were added to any pond where bluegills had spawned previously, no young goldfish were produced. Other fish, such as darters and green sunfish have also prevented the reproduction of goldfish under similar circumstances.

Usefulness of goldfish.—A goldfish-largemouth bass fingerling combination produced the highest poundage of large bass (140 pounds per acre) of any of the combinations used. However, the goldfish as a forage minnow does not appear promising because this species rapidly grows too large for bass to eat, and so many large goldfish accumulate by the end of one year that reproduction ceases. Large goldfish were found to compete seriously with bluegills for food, but where bluegills were present at rates of 1,000 or more per acre of water, they prevented reproduction of goldfish by eating the eggs. . Goldfish were unable to reproduce in any pond if bluegills had hatched previously.

In a new fertilized pond that contained 200 or fewer bluegills per acre, goldfish were able to reproduce if they were large enough to spawn early the first spring before time for bluegill reproduction. Under these conditions the bluegills had so much food that they did not eat goldfish eggs. In ponds containing bluegills and largemouth bass, therefore, goldfish may be safely used as a bait minnow. The few that escape may grow to large size, but they will be unable to reproduce and become numerous enough to constitute a nuisance in the pond. In Alabama a number of old ponds of 10 to 18 acres where goldfish had been used as a bait minnow over a 10-year period, were drained and none contained more than 2 or 3 large goldfish, some weighing as much as 3 pounds.

BLUEGILLS AS FORAGE FISH

Reproduction and food.—Bluegills have been found on beds in the latter part of March at Auburn, but almost invariably no young bluegills were hatched until the last of May or the first of June. The earliest eggs laid were usually eaten by the males which were supposedly guarding the nests. Over 70 percent of the males caught off beds in April in one pond were found upon examination of the stomachs to have been eating eggs. In this same pond, heavy hatches of bluegills were produced in June and throughout the rest of the summer. When crowded, bluegills produced no young. Where sufficient food was available, they produced young fish in large numbers each month from June to October.

Bluegills fed mainly upon water insects and small Crustacea. When very small fish were available, they became a considerable part of the bluegill diet. Bluegills also fed upon various aquatic weeds and upon filamentous algae, but did not grow well on these foods.

Bluegills and largemouth bass fry.—In the first experiment (Table 1) 200 bluegills per acre were stocked November 18, 1940, and 200 bass fry added the following May 8. The pond was drained November 27, 1941, when the bass were about 7 months old. At that time, there were 62.4 pounds of largemouth bass and 82.2 pounds of bluegills, or a total of 144.6 pounds of fish per acre of water. Similar experiments with golden shiners yielded 74 pounds of bass, and with gizzard shad 106 pounds of bass per acre.

Bluegills and largemouth bass fingerlings.—In the second experiment (Table 2) 200 bluegills per acre were stocked November 18, 1940, and 200 largemouth bass fingerlings added the following October 1. The pond was drained October 29, 1942, approximately one year after the addition of the bass.

This combination produced 103.2 pounds of largemouth bass and 261.6 pounds of bluegills, or a total of 364.8 pounds of fish per acre. Similar

TABLE 5.—*Production of fish in ponds stocked with bluegill and largemouth bass combinations*

[Expressed as numbers and pounds per acre at time of drainage]

Year	Stocked per acre	Largemouth bass		Bluegills		Total pounds
		Number	Pounds	Number	Pounds	
1945	1,500 bluegills[1] + 120 bass fry[2]	112	59.0	33,072	176.0	235.0
1945	1,500 bluegills[1] + 120 bass fry[2]	80	32.0	27,784	214.0	246.0
1945	1,500 bluegills[1] + 120 bass fry[2]	92	48.0	22,196	228.0	276.0
1944	1,500 bluegills[3] + 148 bass fry[4]	56	38.0	72,413	251.6	289.6
1944	1,500 bluegills[3] + 148 bass fry[4]	68	28.0	40,455	260.0	288.0
1944	1,500 bluegills[3] + 148 bass fry[4]	40	30.0	53,200	250.0	280.0

[1] Stocked Nov. 27, 1944, total weight 6.0 pounds
[2] Stocked April 13, 1945, total weight 0.02 pound, pond drained Nov. 19, 1945
[3] Stocked Nov. 15, 1943, total weight 9.3 pounds
[4] Stocked May 17, 1944, total weight 0.5 ounce, pond drained Nov. 4, 1944

experiments with goldfish yielded 169.2 pounds of largemouth bass and with golden shiners 118 pounds of bass per acre.

Other bluegill-largemouth bass combinations.—In Table 5 is given the production of bluegills and bass where ponds were stocked with 1,500 bluegills in November and 120 or 148 largemouth bass fry per acre the next spring. The ponds were drained the following November when the bass were approximately 7 months old .

The average production in the 1945 experiments with 120 bass fry per acre was 46.3 pounds of largemouth bass and 206 pounds of bluegills, or a total of 252.3 pounds of fish per acre.

The average production in the 1944 experiments with 148 bass fry per acre was 32 pounds of largemouth bass and 253.8 pounds of bluegills, or a total of 285.8 pounds of fish per acre. Variations noted in the table with the same treatment are normal in experiments of this kind. Average survival of largemouth bass, where stocked at the rate of 120 bass fry per acre, was 78.9 percent, and where stocked with 148 bass fry, 36.9 percent. Reasons for such variations are unknown. Nevertheless, the total productions in pounds per acre are in reasonably close agreement.

Usefulness of bluegills.—It should be noted that in the foregoing experiments, the higher average production of largemouth bass was 46.3 pounds per acre. Where experiments were continued until the bass were 1 years old, the average weight of the adult bluegills increased approximately 33 percent and of the adult bass approximately 25 percent. If fishing was not begun then, the bass and bluegills ceased growth.

When a pond was fished, the large bluegills were reduced in number. This reduction left more food for those that remained and also enabled food organisms to increase by temporarily releasing predation pressure. Consequently, the remaining bluegills produced larger crops of young fish for bass food. The heavy removal of largemouth bass by fishing also enabled the young bluegills to grow to a larger size before being eaten by the bass. As a result, the average catch of largemouth bass from ponds fished for both species has been approximately 40 pounds per acre, and, if the pond was drained at the end of the season, approximately an equal poundage of bass was found still in the pond. The periodic removal of fish, therefore, acts, within limits, to increase production of largemouth bass.

GAMBUSIA AS A FORAGE MINNOW

Reproduction and food.—*Gambusia* produced living young from April or May until fall. They fed largely upon microcrustaceans and various aquatic insects and also to some extent upon newly hatched fish.

Gambusia *and largemouth bass fingerlings.*—One pond was stocked with 280 *Gambusia* per acre November 11, 1940, and 100 bass fingerlings December 8, 1940. The pond was drained on November 27, 1941.

The *Gambusia* were entirely eliminated during the spring months and when the pond was drained, it contained only largemouth bass.

At that time 56 large bass, weighing 38 pounds, and 1,252 small bass, weighing 132 pounds, or a total of 170 pounds per acre, were recovered.

Usefulness of Gambusia.—The small size of the adult *Gambusia* prevented their maintaining themselves in ponds containing bass. Although the total production of largemouth bass was the highest of any treatment, 132 pounds of this amount was bass fingerlings. Apparently, the presence of any of the forage fishes used in these experiments reduced the weight of small bass produced in a pond. Any of the forage fish used, however, produced a higher poundage of large bass than did the largemouth bass-*Gambusia* combination.

Comparative Values of Several Forage Species

From the above experiments, it may be generalized that in the presence of largemouth black bass, forage fish, which in the adult form are not too large for bass to eat, cannot maintain their numbers in the absence of abundant cover and tend to disappear from such ponds. Even in the presence of cover, they tend rapidly to become a minor part of the pond population.

Forage species that rapidly grow to a size too big for largemouth bass to eat tend to become a major part of the pond population, and in so doing may become overcrowded to the extent that their reproductive rate declines seriously. This crowding will eventually reduce the production of largemouth bass in the pond and may, by direct competition for food, seriously reduce the production of other desirable species.

If such large, fast-growing species are to be of continuing value in the production of forage fish for largemouth bass, the adult population must be greatly reduced each year in order to stimulate spawning. To some extent this reduction occurs as a result of natural mortality, but with most species natural mortality is not normally sufficient to accomplish the desired purpose. When bluegills are used as a forage fish, the adults are thinned by fishermen, but no effective methods have been developed for such species as the gizzard shad.

The bluegill appears to be the most desirable as a forage fish of the species tested, although its use did not result in the highest largemouth bass production in short-time experiments. The results indicated, however, that over a period of 3 or more years it would give higher bass production than any of the other species tried. Golden shiners gave increased largemouth bass production for a period of 1 or 2 years, but eventually became a minor factor in the pond, because the number of brood shiners was rapidly reduced by the bass. Gizzard shad gave increased largemouth bass production for 1 to 2 years, but the young rapidly grew too large for bass to eat, and the accumulation of these large fish reduced their own spawning rate and greatly reduced bluegill production.

Goldfish could not be used as a forage fish with both bluegills and largemouth bass because where the pond was adequately stocked with bluegills, this species ate goldfish eggs and entirely prevented reproduction. In a largemouth bass-goldfish combination, therefore, the goldfish spawned heavily the first spring but did not spawn during the second year. *Gambusia* were unsatisfactory as a forage minnow because the largemouth bass almost entirely eliminated them within a few months.

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THE RATE OF GROWTH AND SEX RATIO FOR SEVEN MICHIGAN FISHES

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Abstract

The average size for the various age groups is presented for seven Michigan fishes: the bluegill (*Lepomis m. macrochirus*), yellow perch (*Perca flavescens*), pumpkinseed (*Lepomis gibbosus*), rock bass (*Ambloplites r. rupestris*), largemouth black bass (*Micropterus salmoides*), smallmouth black bass (*Micropterus d. dolomieu*), and the black crappie (*Pomoxis nigro-maculatus*). Ages were determined for 25,723 specimens. Only two species showed consistent sex differences in growth rate. The female yellow perch grew more rapidly than did the males, and the male rock bass were consistently larger than the females of corresponding age.

Sex ratio for each of the species also is presented. The percentage of males varied from 39 percent in the yellow perch to 52 percent for the pumpkinseed and black crappie.

Weights for each of the age-groups were calculated from the length-weight equations.

Introduction

The Michigan Institute for Fisheries Research has been collecting information on the more important game and pan fishes since 1931. Included in the materials were many thousands of scale samples, with records of length, weight, and sex for many of the fishes. This paper deals with the age determinations and sex ratios from these samples.

Average Size for the Various Age Groups

Age determinations were made from the scale samples of 25,723 game and pan fishes. The seven species studied were the bluegill, yellow perch, pumpkinseed, rock bass, smallmouth black bass, largemouth black bass, and the black crappie. The samples were taken by the lake-inventory parties of the Institute, by means of a variety of gear, including gill nets of various mesh sizes, seines, fyke nets, trap nets, and rod and line. Some samples were taken by creel-census clerks from catches made by fishermen. Lakes from all parts of the State of Michigan were represented in the collections. Most of the samples were collected between May and October, but every month of the year was represented.

The scale sample was removed from the side of the fish, just below the lateral line, directly under the spiny-dorsal fin. The scales were placed in standard scale envelopes of the Institute with the data on length, weight, sex, date of collection recorded on the envelope. In the laboratory the scales were cleaned and mounted on glass slides in a glycerin-gelatin medium. They were examined on a microprojection apparatus, the ages were assessed, and the data recorded on growth-analysis cards for later tabulation. The samples were first sorted by age group, then by date of collection, sex, and under sex by length. This procedure facilitated further study of the samples. Ages are given as the number of annuli present on the scale. Thus a fish in age-group III would have three annuli plus a varying amount of marginal growth depending upon the time of year in which it was caught. In order to keep comparisons on a calendar-year basis the author interprets the age of the fishes taken between January 1 and the time of annulus formation in the spring as though the annulus was complete at the scale margin. This "virtual" annulus was indicated in the original records of the age of the fish by an asterisk after the age number signifying that the age given is actually one year greater than the number of visible annuli on the scale would indicate.

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[1] Contribution from the Institute for Fisheries Research

No calculations of length were made from scale measurements in this study. The author believes it best not to use calculated lengths until such a time as the body-scale relationship for each of these species can be determined for Michigan waters. Present indications are that few if any of the species treated here have a constant body-scale ratio. A study now in progress will give the necessary information on this relationship. In this paper, therefore, the average size for each age group is based upon the lengths of the fish at the time of capture. Thus it may be that the lengths as presented are somewhat smaller than the actual length at the completion of the full year's growth. This fact may account for some of the difference in growth between Michigan fishes and those reported from other states.

In the preparation of the materials for this study the question arose as to whether different regions of the state might not have different rates of growth. Beckman (1943) in a study on the time of annulus formation was able to delineate three zones within the State of Michigan in which growth began on different dates. The growth-rate materials were separated on the basis of these three zones and the averages for each zone were obtained. Comparisons showed that no consistent growth differences occurred and therefore all lakes were combined and one average derived for the entire state.

Three groupings were made for the species in each zone—male, female, and sex unknown. When more than one collection was available from a lake the average size of each age group was determined as the weighted mean of all collections from each lake. To obtain the average size for each age group from all lakes the simple average was taken.

Only two species showed a consistent sex difference in rate of growth. The female yellow perch were consistently larger than the males of corresponding age and the male rock bass were larger than the females. This phenomenon has been observed by other workers for these same species (Hile, 1941; Eddy and Carlander, 1942; Schneberger, 1935; Hile and Jobes, 1942). For a general growth curve, such as those presented in Figures 1–7, the sexes were combined (including fish for which the sex was unknown) to give a single curve. Tables 1–7 present the data for each sex and for the sexes combined. The weights given in Tables 1–7 were calculated from the length-weight equations derived for these species in an earlier study (Beckman, 1948).

Comparisons were made between the growth made in Michigan waters with that made in some of the other states. As pointed out earlier some of the difference in growth may be attributed to the fact that each Michigan average is based upon actual lengths at time of capture and not upon the calculated lengths at the end of the growing season as was the case with many of the averages reported in the literature. The bluegill in Michigan grew at a rate somewhat slower that that reported for other states; for example, bluegills of age group IV were 6.6 inches in total length whereas they averaged 7.2 inches in Indiana (Ricker, 1942), 6.8 inches in Illinois (Bennett, 1945), and 7.2 inches in Minnesota (Eddy and Carlander, 1942). A similar situation was evidenced by the largemouth black bass; age-group III averaged 10.0 inches in total length in Michigan, 12.7 inches in Minnesota (Eddy and Carlander, 1942), 12.5 inches in Wisconsin (Bennett, 1937), and 10.8 inches in Connecticut (Webster, 1942).

The smallmouth black bass in Michigan grew at a rate about equal to that exhibited in Wisconsin (Bennett, 1938) and better than those reported from Maine (Fuller and Cooper, 1946) and Connecticut (Webster, 1942), but again were behind those from Minnesota (Eddy and Carlander, 1942). Age-group III in Michigan averaged 11.2 inches in total length; those from Maine, 7.8 inches; Connecticut, 9.5 inches; Wisconsin, 11.4 inches; and Minnesota, 13.0 inches.

The yellow perch also were slower growing than those reported from Connecticut and Minnesota where a total length of 7.9 inches was reported for age-group III (Eddy and Carlander, 1942; Webster, 1942), whereas age-group III in Michigan averaged 6.4 inches. For comparisons between the rock bass, black crappie and pumpkinseed only figures from Minnesota (Eddy and Carlander, 1942) covered a sufficient number of waters to give comparable data. In each species the growth rate was better in Minnesota than in Michigan waters.

SEX RATIO

Sex data were available for 18,985 of the fish for which age determinations were made. Tables 1–7 present the numbers of each sex and the percentage of males for each age group. The general trend was toward a decreased percentage of males with increase in age. For all ages combined the yellow perch has the lowest percentage of males (39 percent). This phenomenon of highly unequal representation of the sexes has been noted by others (Weller, 1938; Hile and Jobes, 1942) with varying percentages of males. The older age groups had higher percentages of females. The pumpkinseed and black crappie had the highest percentage of males with 52 percent each.

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TABLE 1.—*The average length at capture for the various age groups, the calculated weight, and the sex ratio for the bluegill in Michigan*
[Based upon 8,159 specimens from 153 lakes]

Age group	Sex	Number of specimens	Total length (inches)	Standard length (millimeters)	Calculated weight (ounces)	Percentage of males
O	Both.....	13	1.7	33	0.03	....
I	Male.....	118	3.6	72	0.46	48
	Female...	130	3.4	68	0.39	
	Both.....	470	3.1	61	0.30	
II	Male.....	213	4.8	95	1.13	46
	Female...	253	4.8	95	1.13	
	Both.....	944	4.3	86	0.81	
III	Male.....	644	5.6	113	1.90	48
	Female...	698	5.7	115	2.01	
	Both.....	1,933	5.4	109	1.69	
IV	Male.....	615	6.7	134	3.25	48
	Female...	671	6.6	132	3.10	
	Both.....	1,774	6.6	132	3.10	
V	Male.....	433	7.4	148	4.41	47
	Female...	487	7.3	146	4.21	
	Both.....	1,308	7.3	146	4.21	
VI	Male....	305	7.9	158	5.41	42
	Female...	409	7.7	154	5.01	
	Both.....	934	7.7	154	5.01	
VII	Male....	123	7.9	158	5.41	36
	Female...	222	8.3	170	6.81	
	Both.....	425	8.2	166	6.31	
VIII	Male.....	53	8.3	170	6.81	31
	Female...	116	8.4	171	7.00	
	Both.....	260	8.4	171	7.00	
IX	Male.....	12	8.3	170	6.81	23
	Female...	40	8.8	178	7.87	
	Both.....	79	8.7	176	7.55	
X	Male....	4	8.6	174	7.30	27
	Female...	11	9.1	184	8.69	
	Both.....	19	8.9	180	7.92	
Total	Male.....	2,520	...	...	....	45
	Female...	3,037	...	...	....	
	Both.....	8,159	...	...	....	

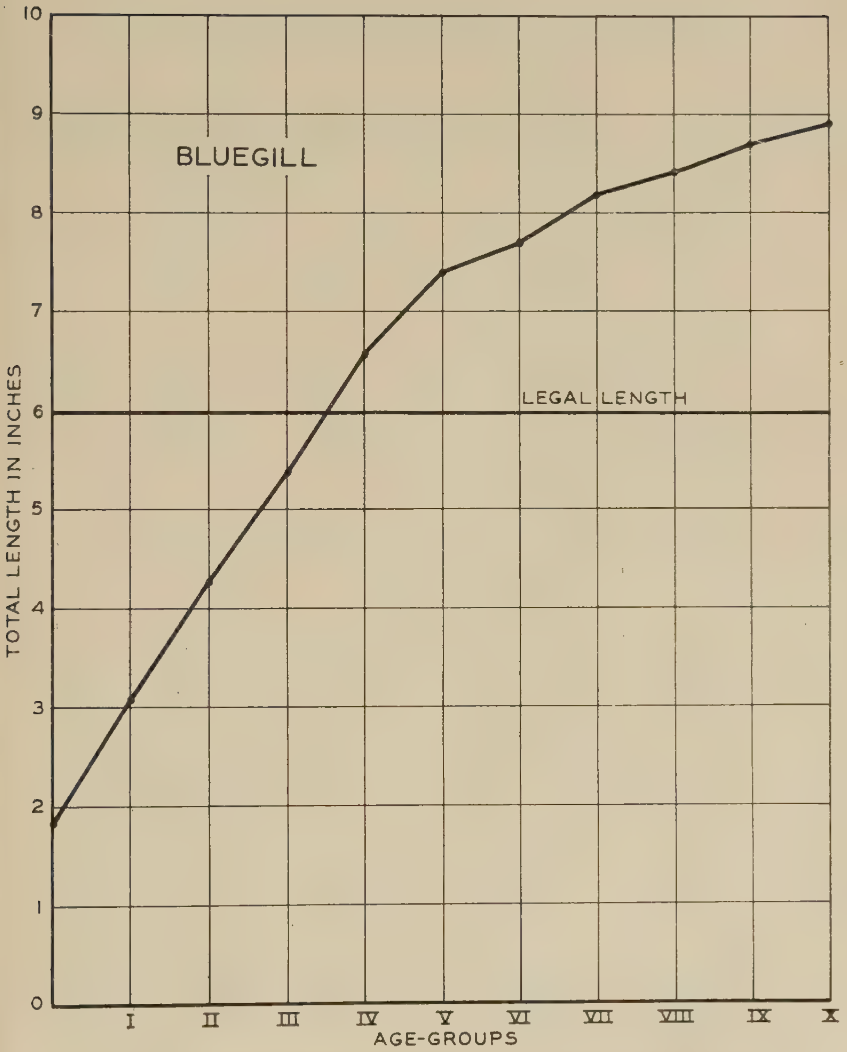

FIGURE 1.—Average length for the various age groups of the bluegill.

TABLE 2.—*The average length at capture for the various age groups, the calculated weight, and the sex ratio for the yellow perch in Michigan*
[Based upon 7,314 specimens from 198 lakes]

Age group	Sex	Number of specimens	Total length (inches)	Standard length (millimeters)	Calculated weight (ounces)	Percentage of males
I	Male....	189	4.5	97	0.56	48
	Female..	208	4.6	99	0.60	
	Both....	596	4.1	88	0.42	
II	Male....	535	5.6	120	1.09	40
	Female..	813	6.1	131	1.45	
	Both....	1,576	5.8	125	1.23	
III	Male....	701	6.0	129	1.38	41
	Female..	1,008	6.7	143	1.90	
	Both....	1,969	6.4	137	1.66	
IV	Male....	456	7.1	152	2.27	38
	Female..	742	7.6	163	2.82	
	Both....	1,390	7.5	160	2.70	
V	Male....	292	8.2	176	3.56	37
	Female..	496	8.7	187	4.27	
	Both....	856	8.5	184	4.02	
VI	Male....	140	9.2	198	5.11	34
	Female..	266	9.6	206	5.75	
	Both....	453	9.5	205	5.64	
VII	Male....	76	9.5	205	5.64	34
	Female..	146	10.7	231	8.22	
	Both....	246	10.4	225	7.55	
VIII	Male....	41	10.1	219	6.95	27
	Female..	109	10.9	236	8.71	
	Both....	155	10.8	233	8.47	
IX	Male....	11	10.9	236	8.71	19
	Female..	47	11.4	247	10.06	
	Both....	59	11.3	245	9.81	
X	Male....	3	12.0	259	11.62	23
	Female..	10	12.0	259	11.62	
	Both....	14	12.0	259	11.62	
Total	Male....	2,444	....	...	.....	39
	Female..	3,853	....	...	.....	
	Both....	7,314	....	...	.....	

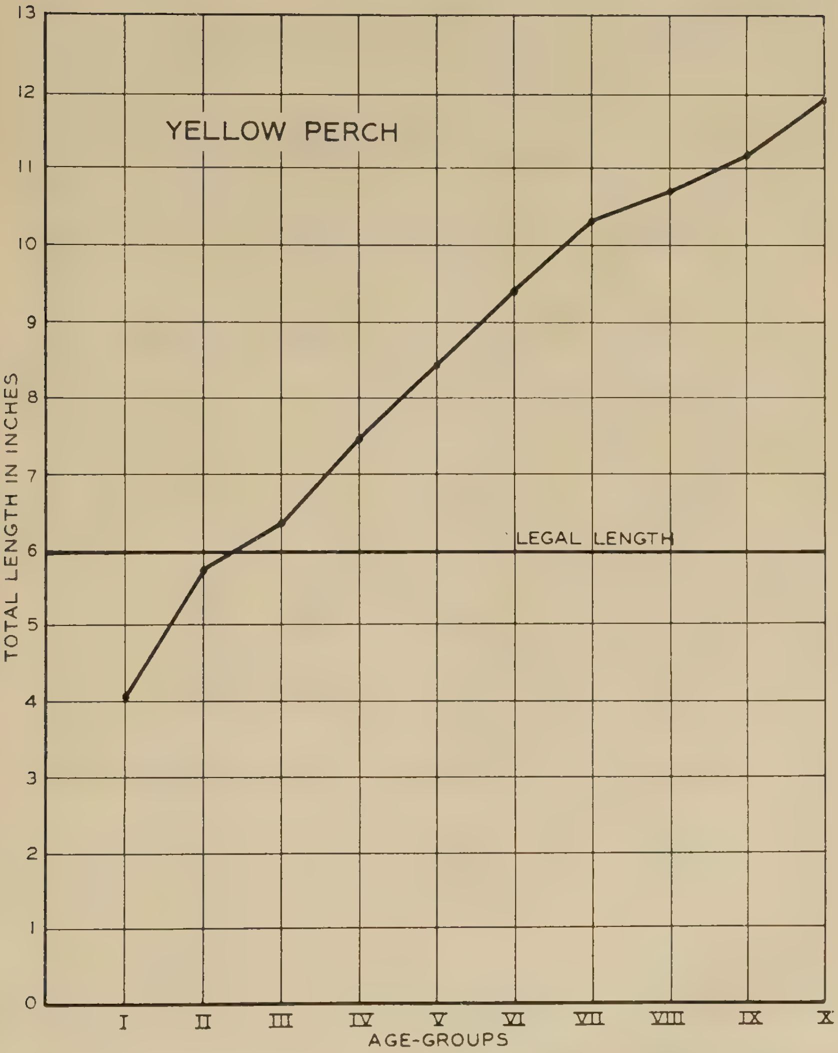

FIGURE 2.—Average length for the various age groups of the yellow perch.

TABLE 3.—*The average length at capture for the various age groups, the calculated weight, and the sex ratio for the pumpkinseed in Michigan*
[Based upon 3,534 specimens from 182 lakes]

Age group	Sex	Number of specimens	Total length (inches)	Standard length (millimeters)	Calculated weight (ounces)	Percentage of males
O	Male....	10	2.1	43	0.09	83
	Female...	2	2.2	45	0.11	
	Both....	20	2.0	41	0.07	
I	Male....	83	2.8	57	0.21	46
	Female..	96	3.2	65	0.35	
	Both....	326	2.9	59	0.25	
II	Male....	180	4.3	87	0.92	58
	Female..	133	4.2	85	0.85	
	Both....	494	4.1	82	0.79	
III	Male....	481	5.2	106	1.73	53
	Female..	435	5.0	102	1.52	
	Both....	1,224	4.9	100	1.43	
IV	Male....	269	5.9	120	2.58	50
	Female..	265	5.9	120	2.58	
	Both....	681	5.7	116	2.31	
V	Male....	180	6.5	134	3.63	54
	Female...	154	6.5	134	3.63	
	Both....	455	6.2	126	3.00	
VI	Male....	105	6.8	139	4.21	54
	Female..	89	6.9	141	4.33	
	Both....	231	6.8	139	4.21	
VII	Male....	38	7.2	147	4.90	50
	Female...	37	7.3	149	5.17	
	Both....	77	7.3	149	5.17	
VIII	Male....	7	7.4	152	5.43	33
	Female...	14	8.4	172	8.11	
	Both....	26	7.8	159	6.31	
Total	Male.....	1,354	...	...	....	52
	Female...	1,229	...	...	....	
	Both.....	3,534	...	...	....	

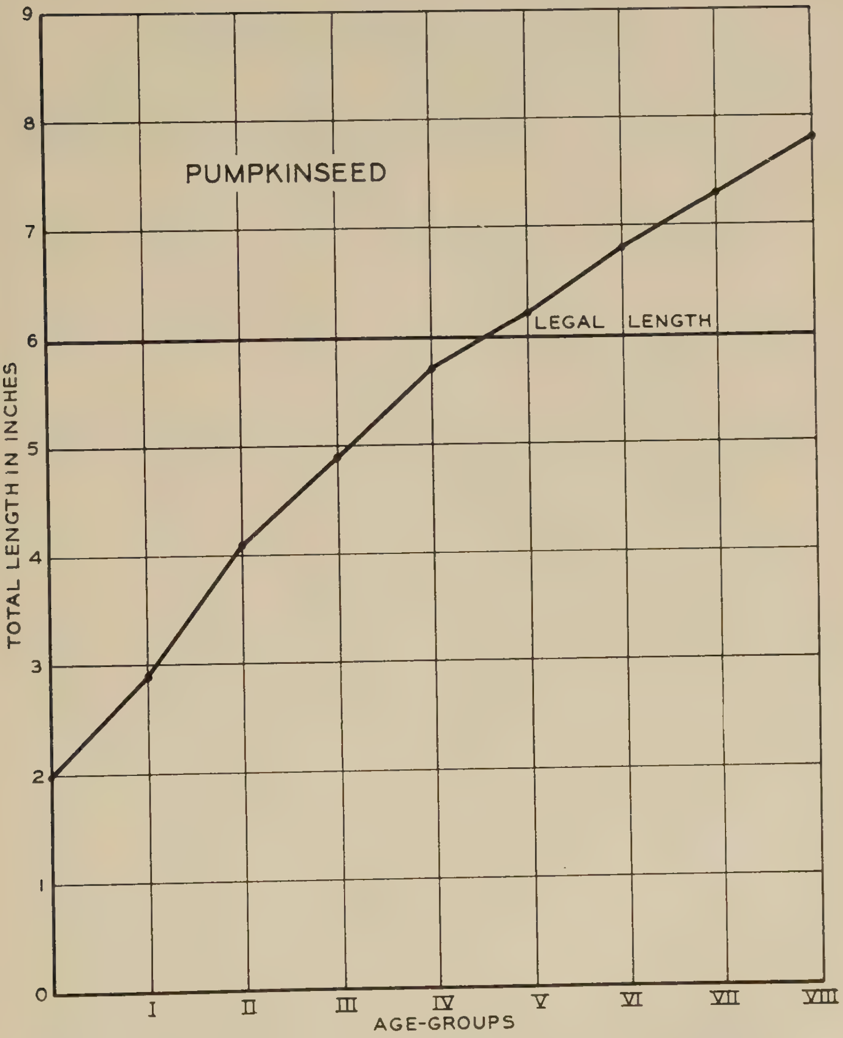

FIGURE 3.—Average length for the various age groups of the pumpkinseed.

TABLE 4.—*The average length at capture for the various age groups, the calculated weight, and the sex ratio for the rock bass in Michigan*
[Based upon 2,466 specimens from 126 lakes]

Age group	Sex	Number of specimens	Total length (inches)	Standard length (millimeters)	Calculated weight (ounces)	Percentage of males
O	Both	17	1.5	30	0.04	....
I	Male	39	3.5	71	0.52	42
	Female	53	2.6	50	0.20	
	Both	176	3.2	65	0.42	
II	Male	107	4.3	86	0.93	61
	Female	69	4.5	90	1.06	
	Both	348	4.3	86	0.93	
III	Male	186	5.4	108	1.83	48
	Female	204	5.2	104	1.66	
	Both	498	5.2	104	1.66	
IV	Male	234	6.6	134	3.21	44
	Female	292	6.2	126	2.93	
	Both	630	6.2	126	2.93	
V	Male	125	7.5	152	5.10	44
	Female	162	7.1	144	4.33	
	Both	338	7.3	148	4.71	
VI	Male	76	8.2	166	6.60	48
	Female	82	8.0	162	6.14	
	Both	183	7.9	160	5.92	
VII	Male	56	8.9	182	8.68	47
	Female	63	8.6	174	7.58	
	Both	129	8.8	178	8.11	
VIII	Male	38	9.5	194	10.48	43
	Female	50	8.5	173	7.27	
	Both	92	9.0	183	8.86	
IX	Male	16	9.3	190	9.88	40
	Female	24	8.6	174	7.58	
	Both	42	9.9	202	11.82	
X	Male	6	10.4	211	13.58	55
	Female	5	10.1	205	12.34	
	Both	13	10.5	213	13.83	
Total	Male	883	...	...	....	47
	Female	1,004	...	...	....	
	Both	2,466	...	...	....	

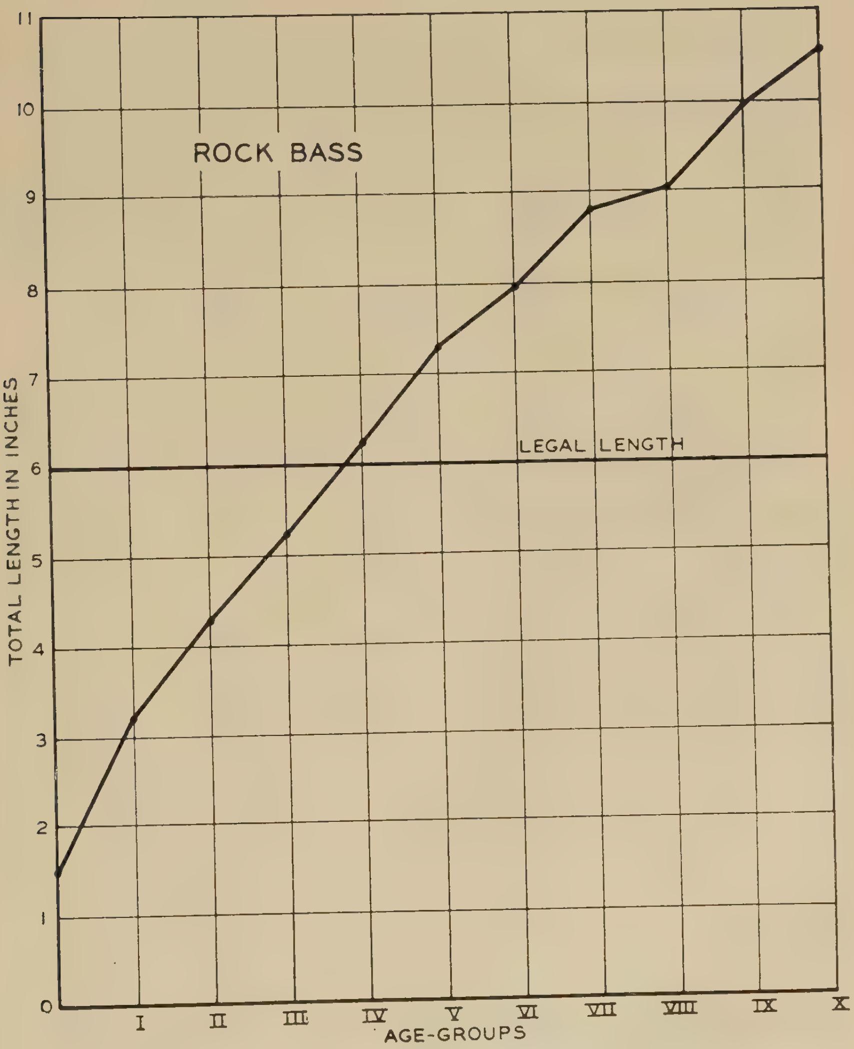

FIGURE 4.—Average length for the various age groups of the rock bass.

TABLE 5.—*The average length at capture for the various age groups and the sex ratio for the black crappie in Michigan*

[Based upon 1,323 specimens from 84 lakes. Data on the length-weight relationship inadequate]

Age group	Sex	Number of specimens	Total length (inches)	Standard length (millimeters)	Percentage of males
II	Male....	205	6.5	131	56
	Female..	161	6.3	127	
	Both....	430	5.9	118	
III	Male....	122	7.8	157	50
	Female..	124	8.0	161	
	Both.....	336	8.0	161	
IV	Male....	102	8.9	179	61
	Female..	66	9.0	181	
	Both....	253	9.0	181	
V	Male....	44	10.0	201	42
	Female...	61	9.8	197	
	Both....	143	9.9	199	
VI	Male....	31	10.0	201	41
	Female...	45	10.9	219	
	Both.....	113	10.7	215	
VII	Male.....	10	11.1	223	32
	Female...	21	11.0	221	
	Both.....	40	11.3	227	
VIII	Female...	4	10.6	213	0
	Both.....	8	11.6	233	
Total	Male.....	515	...	...	52
	Female...	484	...	...	
	Both.....	1,323	...	...	

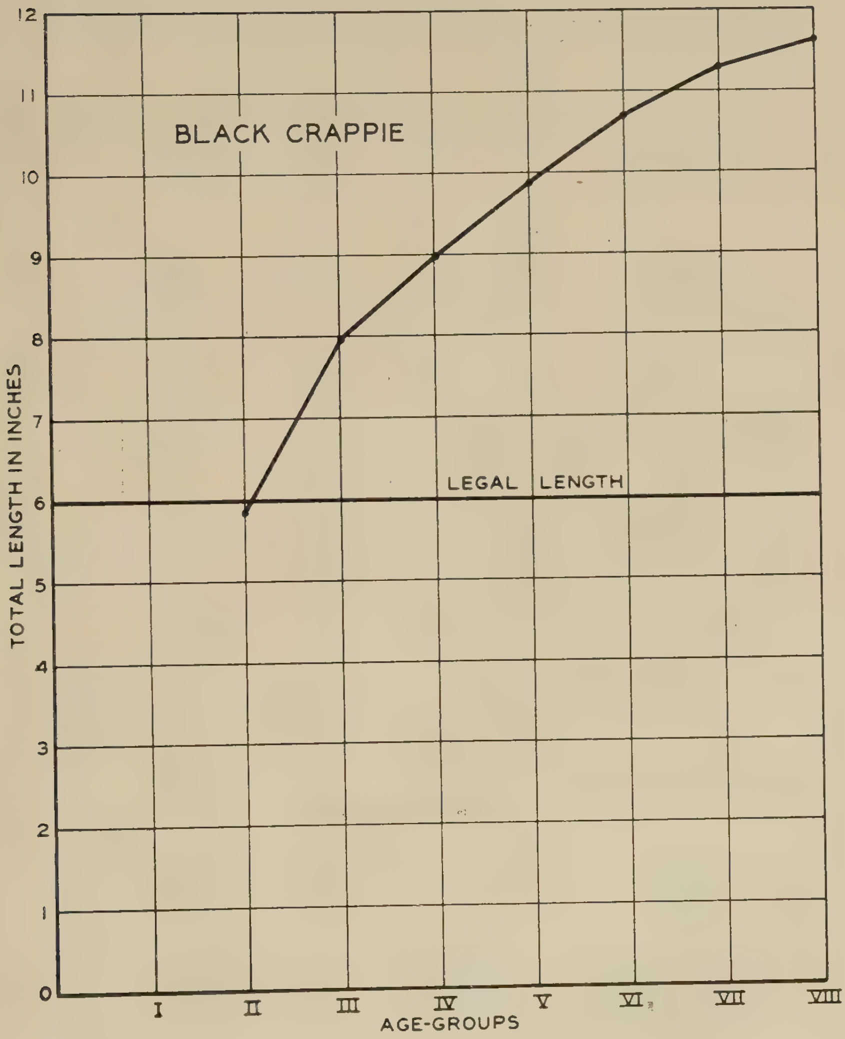

FIGURE 5.—Average length for the various age groups of the black crappie.

TABLE 6.—*The average length at capture for the various age groups, the calculated weight, and the sex ratio for the largemouth black bass in Michigan*
[Based upon 2,307 specimens from 175 lakes]

Age group	Sex	Number of specimens	Total length (inches)	Standard length (millimeters)	Calculated weight (ounces)	Percentage of males
O	Male	4	3.6	76	0.35	40
	Female	6	3.7	78	0.39	
	Both	174	3.3	71	0.28	
I	Male	77	6.3	130	1.80	53
	Female	67	7.1	148	2.61	
	Both	321	6.1	127	1.65	
II	Male	139	9.0	190	5.58	49
	Female	142	8.8	186	5.18	
	Both	419	8.7	184	4.91	
III	Male	169	10.5	219	8.30	51
	Female	163	9.7	205	6.95	
	Both	505	10.0	211	7.53	
IV	Male	92	11.4	240	11.14	45
	Female	112	12.1	252	12.78	
	Both	368	12.1	252	12.78	
V	Male	74	13.3	280	17.64	51
	Female	70	13.6	284	18.31	
	Both	285	13.7	287	19.01	
VI	Male	25	14.7	309	23.70	48
	Female	27	15.1	314	24.87	
	Both	111	15.1	314	24.87	
VII	Male	10	15.7	329	28.60	40
	Female	15	16.7	358	36.82	
	Both	71	16.1	348	34.71	
VIII	Male	5	17.1	362	38.78	36
	Female	9	19.0	402	50.83	
	Both	33	17.7	372	42.04	
IX	Male	1	18.0	389	46.76	17
	Female	5	17.7	372	42.04	
	Both	20	17.9	386	46.29	
Total	Male	596	...	...	....	49
	Female	617	...	...	....	
	Both	2,307	...	...	....	

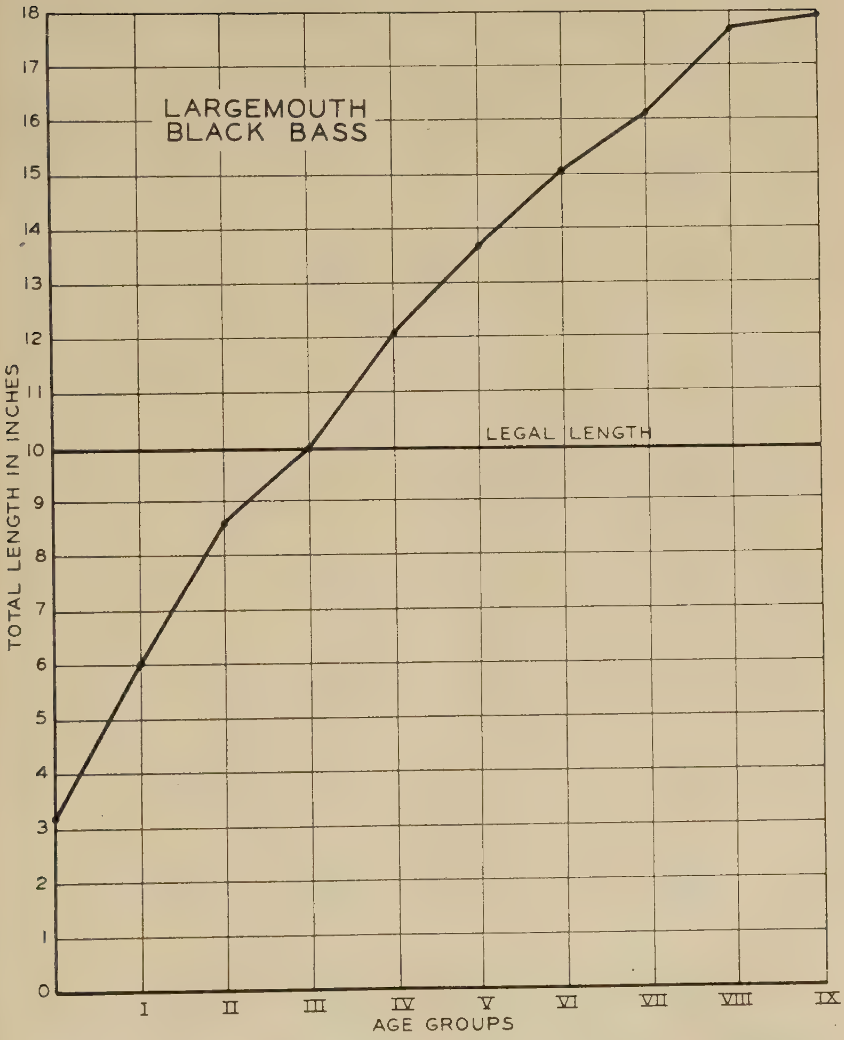

FIGURE 6.—Average length for the various age groups of the largemouth black bass.

TABLE 7.—*The average length at capture for the various age groups, the calculated weight, and the sex ratio for the smallmouth black bass in Michigan*
[Based upon 620 specimens from 88 lakes]

Age group	Sex	Number of specimens	Total length (inches)	Standard length (millimeters)	Calculated weight (ounces)	Percentage of males
O	Male....	2	3.5	75	0.34	40
	Female...	3	3.2	68	0.25	
	Both.....	33	3.3	71	0.28	
I	Male....	20	6.3	130	1.94	61
	Female..	13	6.3	130	1.94	
	Both.....	53	5.9	124	1.65	
II	Male.....	40	9.5	196	6.70	57
	Female..	30	9.6	198	6.81	
	Both.....	95	9.0	189	5.78	
III	Male.....	51	11.2	233	11.13	49
	Female..	53	11.2	233	11.13	
	Both....	158	11.2	233	11.13	
IV	Male....	48	13.6	283	20.02	44
	Female...	62	12.8	265	16.45	
	Both.....	128	13.3	278	19.12	
V	Male.....	28	15.1	315	27.72	41
	Female...	40	15.0	312	26.79	
	Both.....	79	15.0	312	26.79	
VI	Male....	14	15.7	330	32.27	42
	Female...	19	15.3	318	28.80	
	Both.....	45	15.3	318	28.80	
VII	Male.....	8	16.7	348	38.04	47
	Female...	9	17.0	354	40.12	
	Both.....	20	16.4	339	34.93	
VIII	Male.....	2	17.4	361	42.43	25
	Female...	6	16.9	353	39.90	
	Both.....	9	16.8	351	38.71	
Total	Male.....	213	...	...	....	47
	Female...	236	...	...	....	
	Both.....	620	...	...	....	

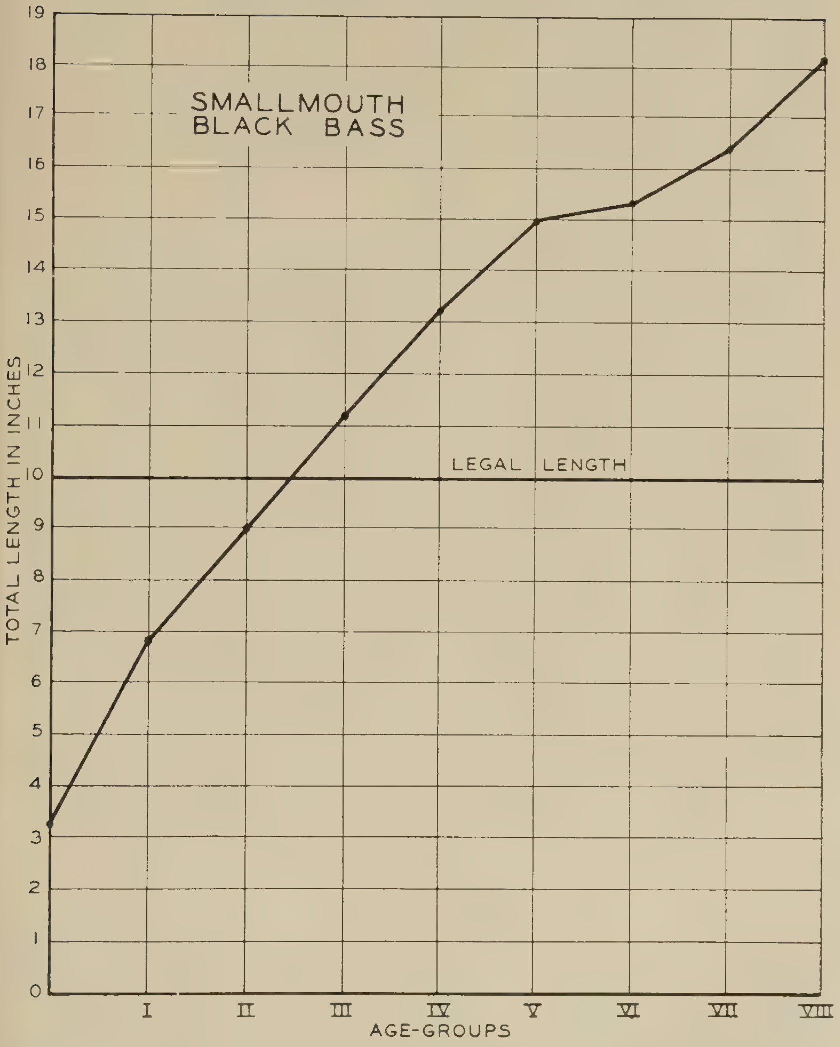

FIGURE 7.—Average length for the various age groups of the smallmouth black bass.

DOSAGE OF SULFAMERAZINE IN THE TREATMENT OF FURUNCULOSIS IN BROOK TROUT, *SALVELINUS FONTINALIS*

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Abstract

To determine the most effective dosage of sulfamerazine in the treatment of furunculosis in brook trout, two experiments were run.

In the first experiment, yearlings were used and the daily dosage rates were 4, 8, and 12 grams of sulfamerazine per 100 pounds of fish. In the lots treated with sulfamerazine, mortality was brought under control within 15 days and was less than a quarter as high as in the controls. Results with the 4-gram rate were nearly as good as with the higher rates. Treatment was continued for 10 days or more after mortality dropped to zero, and recurrences were few. A large number of the dead were checked bacteriologically for furunculosis.

In the second experiment fingerlings in an early stage of a furunculosis epizootic were used and the daily dosage rates were 2, 4 and 6 grams per 100 pounds of fish. Losses in the controls were extremely heavy, with only 6-percent survival. Losses were heavy in all lots, but in those treated at the 4-gram and 6-gram rates, survival was 10 times as high as in the controls. Mortality declined sooner with the 6-gram than with the 4-gram rate, and recurrence was almost eliminated by treatment, at the higher rate, for 10 days after mortality dropped to zero. Discontinuance of treatment as late as 4 days after the discontinuance of mortality was followed by resumption of mortality at a considerable rate. In the treated lots, late dead were small thin fish which evidently had received little food and drug. Dead fish were "spot-checked" for furunculosis.

The recommended daily dosage rate is 6 grams per 100 pounds of fish, to be continued for 10 days after mortality stops and for a total of at least 3 weeks. Other recommendations include: the early elimination of undersized fish; the prompt removal of dead and dying fish; the maintenance of clean troughs and pools; and strict observation of all sanitary measures practiced in the control of infectious diseases.

Introduction

In the initial experiment in 1945 (Gutsell 1946, 1946a, 1947, 1947a), it was shown that sulfamerazine, mixed with the food, is remarkably effective in the treatment of furunculosis in brook trout. Although it was clear that a dosage rate of 8 grams of the drug per day per 100 pounds of fish was effective and that lighter rates were at least beneficial, the problem of dosage remained largely unexplored.

The present paper is based on two experiments on dosage run in 1946. In the first of these, yearling brook trout were used and daily dosages of 4, 8 and 12 grams per 100 pounds of fish tried. In the second dosage experiment, the fish were fingerling brook trout, and the rates tried were 2, 4, and 6 grams per day per 100 pounds of fish. In both experiments untreated fish were kept as controls.

To insure as even distribution as practical, the sulfamerazine was carefully mixed with the dry feed before that was mixed with the meat (spleen) and water. For optimum cohesion of the food mix, 4 percent of salt was included in the dry feed. The proportion of meat, dry feed and water was 2–2–1 by weight. Except for the controls, no food which did not contain the drug was used during the periods of treatment. Within each block or group of adjacent troughs, assignment of treatment was by random selection.

Dead fish were removed each morning. Because both experiments were begun in the afternoon, there are no mortality figures, in tables or graphs, for the first day of either experiment.

A large portion of the dead yearlings was examined bacteriologically for the presence of *Bacterium salmonicida*. In the second experiment, such examination was limited to spot-checking where that seemed indicated.

Bacteriological examination was made in the following manner. Dead trout were surface-sterilized by immersion for about 5 minutes in a strong hypochlorite solution, or in a 1:100 solution of commercial Roccal. To remove the disinfectant, the area where the incision was to be made was swabbed with ethyl alcohol. Next a transverse cut was made behind the dorsal fin and a blood sample taken from the exposed kidney or dorsal vein by means of a loop or Pasteur pipette (Gutsell, 1947).

Several media were tried in order to find one producing fast growth and facilitating indentification. The medium finally chosen was made up as follows (the pH of the medium was 7.2–7.4):

Tryptic digest of casein	7 grams
Yeast extract	3 grams
Sodium chloride	2.5 grams
Water	1 liter

On this medium, solidified with 1.5 percent of agar, a good growth of *B. salmonicida* developed within 24 hours at 20°C. After 2–3 days, there appeared a diffused cherry-brownish pigment which later became dark brown. With 0.1 percent of agar, the medium was semi-solid, and yielded granular growth within 24 hours. The semi-solid medium was used to determine the characteristic lack of motility of *B. salmonicida* and thereby to speed up and make more reliable the presumptive tests for its presence.

FIRST DOSAGE EXPERIMENT

The yearling brook trout used in the first experiment were a rather mixed lot. Those first selected were from Lot A in which mortality from furunculosis had been heavy for several weeks. To secure an ample number per trough, other yearling brook trout were added. These were taken from Lot B, which had been treated for, and apparently cured of, furunculosis in January, and from a Lot C, which was free or nearly free from furunculosis.

When feeding and tratment were begun on May 18, each of the 16 troughs contained: 67 unmarked fish from Lot A; 5 fish from Lot B, marked by removing the left ventral fin; and 50 from Lot C, with left pectoral fin removed. In addition, each of the 8 troughs of the first block contained 20, and each of the 8 troughs of the second block 15 unmarked fish from Lot C.

The initial weight of fish per trough varied from 10 pounds to 11 pounds, 10 ounces (4,536–5,273 grams).

Besides the variation in dosage level (4, 8 and 12 grams of sulfamerazine per day per 100 pounds of fish), variation in intervals between doses was tried. In each block the fish in two troughs were treated at the same rate. One of these was fed once a day, the other at 8-hour intervals. This applied to the controls also.

Allotments of sulfamerazine were adjusted on June 5 and 11; allot-

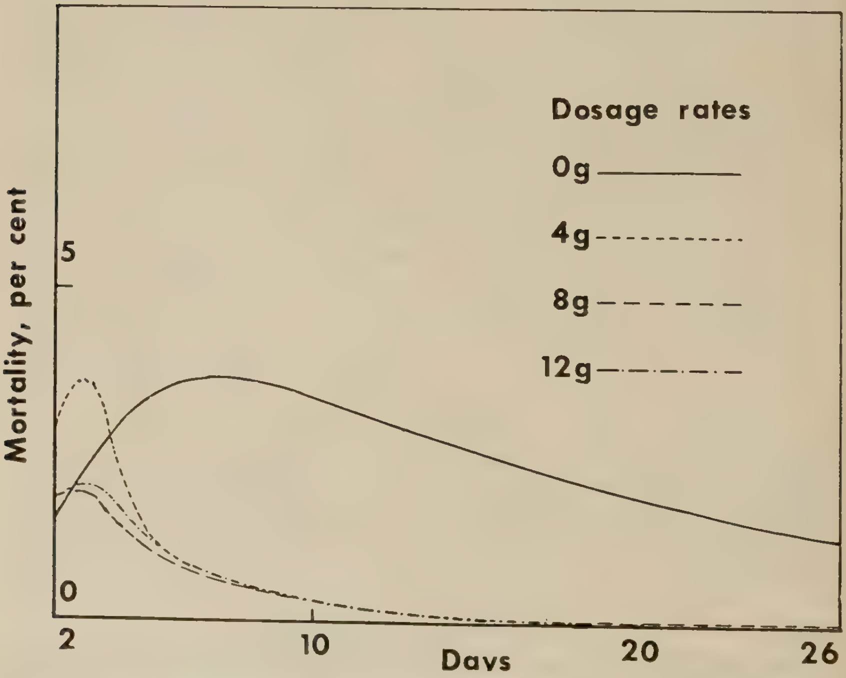

Figure 1.—Percentage mortality per day in brook trout yearlings treated at different daily dosage rates of sulfamerazine.

ments of food on June 5, 11, and 25. The adjustments made on June 5 were based on estimations of fish weights, the others on reweighings.

To facilitate comparison, the time through which the experiment was run was divided into five periods as follows: Period A, 14 days; Period B, 11 days; Period C, 13 days; Period D, 15 days and Period E, 15 days.

Treatment was discontinued at the end of Period B in Block 1, but was continued through Period C in Block 2. The remainder of the time, because of its length, was divided into two periods, D and E, as noted above.

TABLE 1.—*Daily mortalities of brook trout yearlings treated at different daily dosage rates of sulfamerazine*

[Presented as numbers and as percent of those present the preceding day. Initial number for each treatment, 558 fish]

Days	Controls		4-gram rate		8-gram rate		12-gram rate	
	Numbers	Percent	Numbers	Percent	Numbers	Percent	Numbers	Percent
2	5	0.9	13	2.3	10	1.8	10	1.8
3	14	2.5	21	3.9	11	2.0	10	1.8
4	16	3.0	6	1.1	5	0.9	10	1.9
5	19	3.6	5	1.0	6	1.1	5	0.9
6	21	4.2	3	0.6	4	0.8	3	0.6
7	17	3.5	2	0.4	4	0.8	3	0.6
8	14	3.0	4	0.8	2	0.4	1	0.2
9	16	3.5	3	0.6	2	0.4	7	1.4
10	11	2.5	1	0.2	3	0.6	2	0.4
11	23	5.4	1	0.2	0	0.0	2	0.4
12	7	1.7	4	0.8	3	0.6	1	0.2
13	12	3.0	1	0.2	0	0.0	1	0.2
14	8	2.1	1	0.2	3	0.6	1	0.2
15	7	1.9	0	0.0	0	0.0	0	0.0
16	9	2.4	1	0.2	0	0.0	3[2]	0.6[2]
17	12	3.3	0	0.0	0	0.0	0	0.0
18	10	2.9	0	0.0	0	0.0	2[1]	0.4[1]
19	6	1.8	1[1]	0.2[1]	0	0.0	0	0.0
20	0	0.0	0	0.0	0	0.0	2[3]	0.4[3]
21	8	2.4	1	0.2	0	0.0	1[1]	0.2[1]
22	3	0.9	0	0.0	0	0 0	0	0.0
23	5	1.6	0	0.0	1[1]	0.2[1]	1[1]	0.2[1]
24	12	3.8	0	0.0	0	0.0	0	0.0
25	2	0.7	0	0.0	0	0.0	0	0.0
26	4	1.3	0	0.0	1	0.2	0	0.0

[1] Not from furunculosis

[2] Two of these not from furunculosis

[3] One of these not from furunculosis

TABLE 2.—*Mortality*[1] *by periods*[2] *in brook trout yearlings treated at different daily dosage rates of sulfamerazine*

Periods	Item	Controls					4-gram rate					8-gram rate					12-gram rate				
		A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
A and B (24-hour intervals)	Initial number of fish	142	...	...	...	...	142	...	...	...	...	142	...	...	...	...	142	...	...	...	...
	Number dead per period	58	20	11	7	3	17	1	1	1	1	11	0	0	0	0	12	0	0	0	0
	Percentage dead per period[3]	38.7	23.0	16.4	12.5	6.1	12.0	0.8	0.8	0.8	0.8	7.7	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0
A and B (8-hour intervals)	Initial number of fish	142	...	...	...	...	142	...	...	...	...	142	...	...	...	...	142	...	...	...	...
	Number dead per period	45	26	4	1	3	16	0	1	3	3	14	0	0	2	1	7	0	0	0	0
	Percentage dead per period[3]	31.7	26.8	5.6	1.5	4.5	10.6	0.0	0.8	2.4	2.5	9.9	0.0	0.0	1.6	0.8	4.9	0.0	0.0	0.0	0.0
A, B, and C (24-hour intervals)	Initial number of fish	137	...	...	...	...	137	...	...	...	...	137	...	...	...	...	137	...	...	...	...
	Number dead per period	43	12	11	9	3	21	1	0	0	0	17	0	0	0	0	23	0	0	0	0
	Percentage dead per period[3]	31.4	12.8	13.4	12.7	4.8	15.3	0.9	0.0	0.0	0.0	12.4	0.0	0.0	0.0	0.0	16.8	0.0	0.0	0.0	0.0
A, B, and C (8-hour intervals)	Initial number of fish	137	...	...	...	...	137	...	...	...	...	137	...	...	...	...	137	...	...	...	...
	Number dead per period	40	16	14	9	2	11	0	0	0	5	10	0	0	0	0	15	2	0	1	1
	Percentage dead per period[3]	29.2	16.5	17.3	13.4	3.4	8.0	0.0	0.0	0.0	4.0	7.3	0.0	0.0	0.0	0.0	10.9	1.6	0.0	0.9	0.9
Totals per treatment	Initial number of fish	558					558					558					558				
	Total number dead	332 (333)					81 (84)					56 (64)					60 (76)				
	Total percentage dead	59.5 (59.7)					14.5 (15.1)					10.0 (11.5)					10.8 (13.8)				

[1] Dead found to have furunculosis were excluded, except for data in parentheses which include all the dead

[2] Period A equals 14 days; B equals 11 days; C equals 13 days; D equals 15 days; and E equals 15 days

[3] The percentage mortality per period is based on the number present at the start of the period

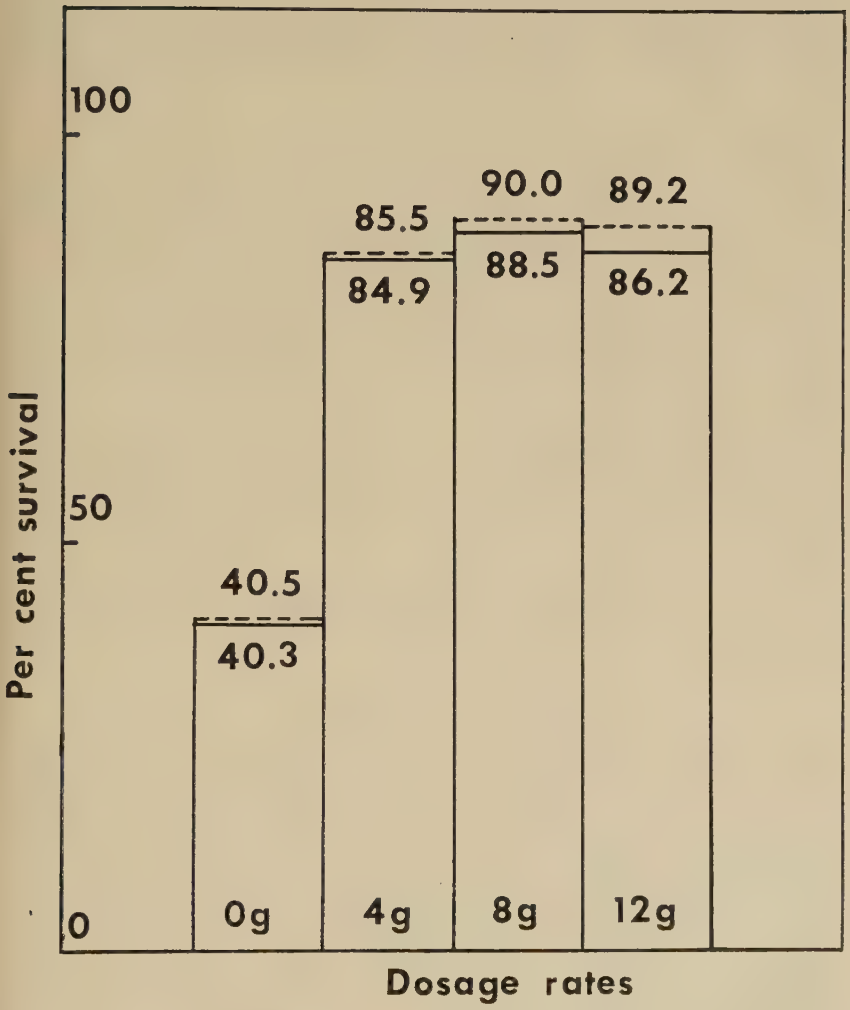

FIGURE 2.—Survival of yearling brook trout treated at different dosage rates of sulfamerazine (the dotted lines in the columns and the upper figures include the trout known to have died from other causes than furunculosis).

Results are presented in Tables 1 and 2 and Figures 1 and 2.

Mortality in the treated lots dropped to zero by the seventeenth day, but in one control lot or another continued to the sixty-third day. The relatively heavy early mortality in the controls was chiefly among the fish with clipped fins. Later mortality was largely among the unmarked fish.

For the various treatments, the mortalities were as follows: controls, 59.5 percent; 4-gram rate, 14.5 percent; 8-gram rate, 10.0 percent; 12-gram rate, 10.8 percent. From these calculations were excluded all dead fish which by bacteriological examination were found free from infection by *B. salmonicida*. Including all dead, the corresponding percentages were: 59.7, 15.1, 11.5, and 13.8.

Both among the controls and among the fish being treated with sulfamerazine, mortality was about 8 percent lower for fish fed at 8-hour intervals than for those fed at 24-hour intervals. On the other hand, late mortality among treated lots was somewhat higher for those fed at 8-hour intervals.

In the trough which received prolonged treatment at the 4-gram rate, the late mortality came after a gap of 50 days, and after minnows with furunculosis had been placed in the trough above it. It is believed that this long-delayed recurrence was due to contamination from this external source.

In this experiment, even the shorter treatment continued for 10 or more days after mortality had stopped. Therefore it is not surprising that there was little difference in mortality between the shorter and the longer period.

Second Dosage Experiment

On May 25, fingerling brook trout, in a pool in which there had been mortality for a few days, appeared to have furunculosis. By May 27 this was confirmed bacteriologically and by May 29 the fish were distributed in 6-pound lots among 12 lower troughs and treatment begun. The troughs were grouped in three blocks of four. The dosage rates were 2, 4, and 6 grams of sulfamerazine per day per 100 pounds of fish. Untreated fish were kept as controls. The fish were reweighed and allotments of food and drug adjusted on June 13 and 25 and July 16.

Results are presented in Table 3 and Figures 3 and 4. Figure 5, which includes photographs of a control and of a treated lot, is a readily appreciated illustration of the immense benefit conferred by suitable treatment of furunculosis with sulfamerazine.

Among the fish treated at the 4-gram and 6-gram rates, mortality generally dropped to zero by the twenty-fifth day, which was taken as terminating Period A. Period B extended from the twenty-sixth to the thirty-seventh day; Period C, from the thirty-eighth to the forty-ninth, and Period D, from the fiftieth to the sixty-third day.

Block 1 received sulfamerazine through Period A, C, and D; Block 2, through Periods A and D; and Block 3, except for one trough, through Periods A and B only. In Block 3, the trough which had been treated at the 2-gram rate, showed appreciable mortality and *B. salmonicida* infection in Period C. This trough received treatment through Periods A, B, and D. All administrations of sulfamerazine in Periods C and D were at a 5-gram rate.

TABLE 3.—*Daily mortalities of brook trout fingerlings treated at different daily dosage rates of sulfamerazine*

[Presented as numbers and as percent of those present the preceding day]

Days	Controls[1]		2-gram rate[2]		4-gram rate[3]		6-gram rate[4]	
	Numbers	Percent	Numbers	Percent	Numbers	Percent	Numbers	Percent
2	95	3.2	114	3.8	82	2.9	91	3.2
3	186	6.4	196	6.9	135	4.9	167	6.0
4	179	6.6	181	6.8	107	4.1	124	4.7
5	269	10.5	233	9.4	141	5.6	137	5.5
6	295	12.9	233	10.4	138	5.8	105	4.4
7	302	15.2	169	8.4	126	5.6	84	3.7
8	270	16.0	183	9.9	81	3.8	70	3.2
9	231	16.3	98	5.9	54	2.7	56	2.7
10	170	14.4	79	5.1	50	2.5	46	2.2
11	141	13.9	48	3.2	32	1.7	38	1.9
12	124	14.2	36	2.5	34	1.8	30	1.5
13	111	14.8	43	3.1	18	1.0	12	0.6
14	74	11.6	30	2.2	16	0.9	18	0.9
15	69	12.2	24	1.8	14	0.8	8	0.4
16	54	10.9	13	1.0	8	0.4	4	0.2
17	38	8.6	15	1.2	7	0.4	7	0.4
18	40	9.9	11	0.9	5	0.3	6	0.3
19	11	3.0	5	0.4	4	0.2	9	0.5
20	25	7.1	9	0.7	3	0.2	2	0.1
21	16	4.9	8	0.6	7	0.4	3	0.2
22	18	5.8	8	0.6	0	0.0	0	0.0
23	12	4.1	6	0.5	1	0.1	1	0.1
24	10	3.6	2	0.2	2	0.1	0	0.0
25	11	4.1	9	0.7	2	0.1	5[5]	0.3[5]
26	15	5.8	3	0.2	2	0.1	1	0.1

[1] Initial number, 3011
[2] Initial number, 2970
[3] Initial number, 2838
[4] Initial number, 2890
[5] Three of these not from furunculosis

TABLE 4.—*Mortality[1] by periods[2] in brook trout fingerlings treated at different daily dosage rates of sulfamerazine*

Periods	Item	Controls				2-gram rate				4-gram rate				6-gram rate			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
A and D	Initial number of fish	991	....	....	....	947	....	....	....	939	....	....	....	951	....	....	....
	Number dead per period	93	28	2	2	573	53	45	11	372	4	20	18	318	8	44	27
	Percentage dead per period[3]	92.1	35.9	4.0	4.2	60.5	14.2	14.0	4.0	39.6	0.7	3.6	3.3	33.4	1.3	7.1	4.7
A, C, and D	Initial number of fish	1010	....	....	....	988	....	....	....	988	....	....	....	968	....	....	....
	Number dead per period	930	19	2	3	537	24	13	3	401	8	7	2	307	8	15	3
	Percentage dead per period[3]	92.1	23.8	3.3	5.1	54.4	5.3	3.0	0.7	40.6	1.2	1.2	0.3	31.7	1.2	2.3	0.5
A and B	Initial number of fish	1010	....	....	....	...	....	....	....	911	....	....	....	971	....	....	....
	Number dead per period	908	19	0	2	...	...	...	...	294	2	0	11	396	1	0	3
	Percentage dead per period[3]	89.9	78.6	1.2	2.5	...	...	...	...	32.3	0.3	0.0	1.8	40.8	0.2	0.0	0.5
A, B, and D	Initial number of fish	...	....	....	....	1035	....	....	....	...	...	...	...	...	...	...	...
	Number dead per period	...	...	...	...	643	2	5	5	...	...	...	...	...	...	...	...
	Percentage dead per period	...	...	...	...	62.1	0.5	1.3	1.3	...	...	...	...	...	...	...	...
Totals per treatment	Initial number of fish	3011				2970				2838				2890			
	Total number dead	2830 (2832)				1914 (1921)				1138 (1146)				1130 (1140)			
	Total percentage dead	94.0 (94.1)				64.4 (64.7)				40.1 (40.4)				39.1 (39.4)			

[1] Dead found not to have furunculosis were excluded, except for data in parentheses which include all the dead

[2] Period A equals 14 days; B equals 11 days; C equals 13 days and D equals 15 days

[3] The percentage mortality per period is based on the number present at the start of the period

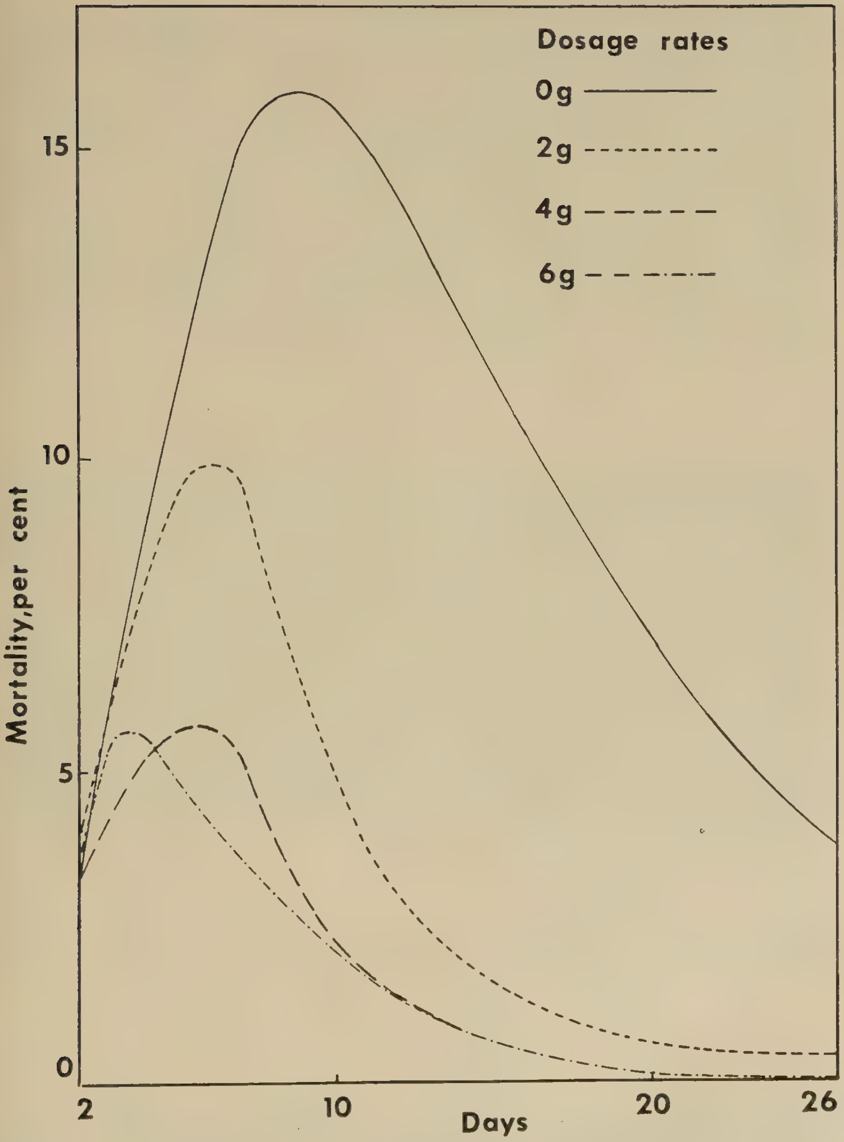

FIGURE 3.—Percentage mortality per day in brook trout fingerlings treated at different daily dosage rates of sulfamerazine.

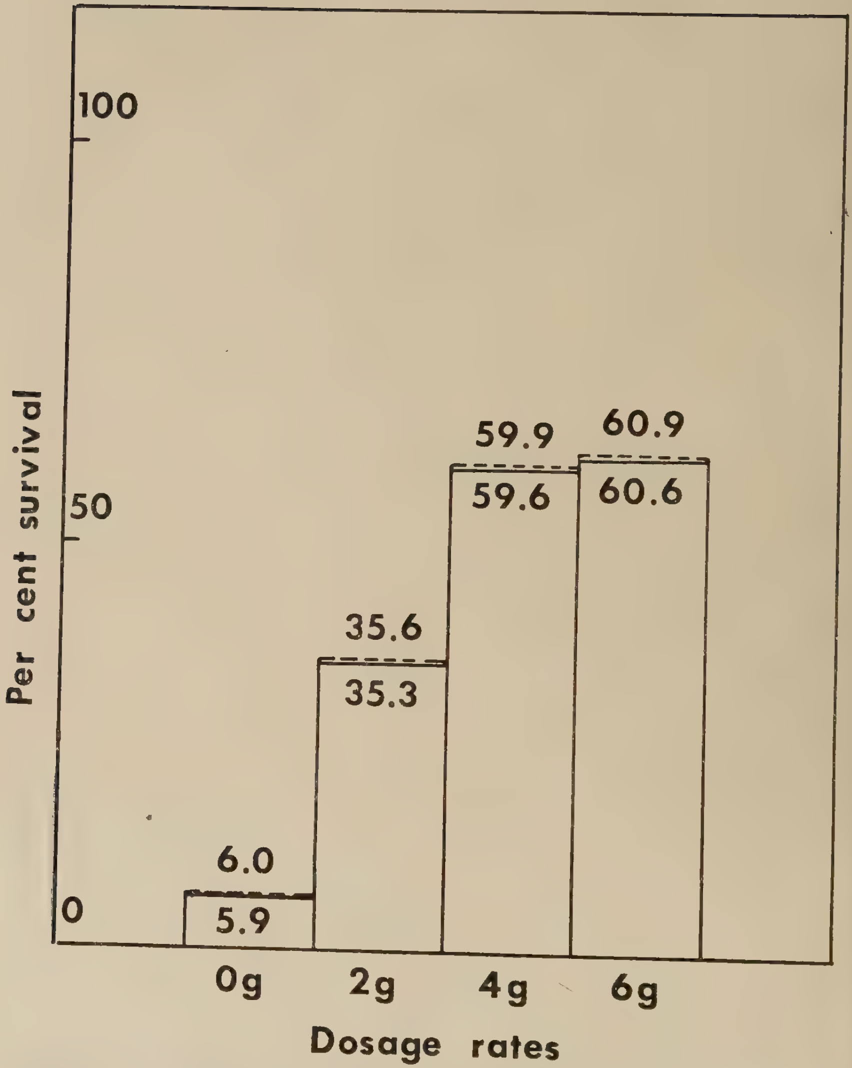

FIGURE 4.—Survival of fingerling brook trout treated at different dosage rates of sulfamerazine (the dotted lines in the columns and the upper figures include the trout known to have died from other causes than furunculosis).

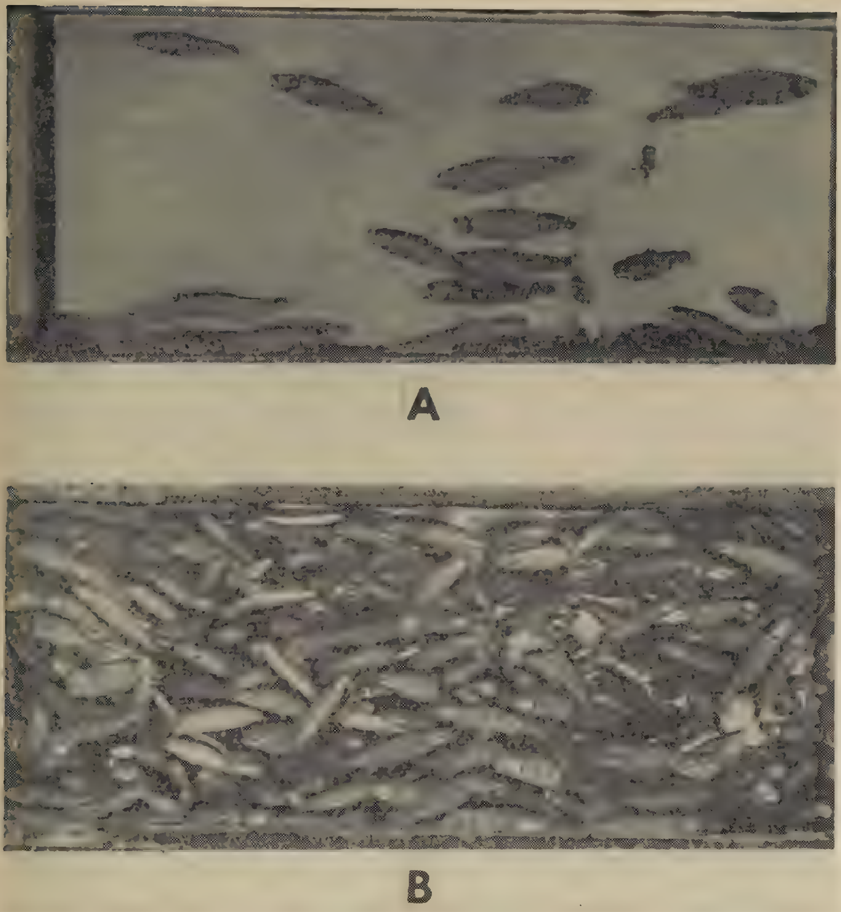

FIGURE 5.—Survival of fingerling brook trout as affected by treatment with sulfamerazine. Remaining trout at the end of the experiment: A, controls; B, treated with 4 grams of sulfamerazine per 100 pounds of fish per day.

The course of the epizootic, without medication, is shown in Tables 3 and 4 and in part in Figure 3. Mortality with *B. salmonicida* infection dropped to zero by the 45th day, but reappeared after 9 days. The loss through the experimental period was tremendous, 94 percent.

The effects of the various treatments through Period A are shown in Table 3 and Figure 3 and the losses accompanying the various later procedures in Table 4. Survivals are shown in Figure 4.

Benefit from treatment at the 2-gram rate was considerable (64-percent loss), but much less than from the heavier dosages.

For the 4-gram and 6-gram rates, treatment through Period A involved treatment for 4 days after mortality stopped for the two lots, one for each rate, in which treatment was discontinued for 24 days. Mortality from furunculosis began again by the ninth day, and was considerable. In the lots for which treatment was resumed after a 12-day lapse, late mortalities were much lower.

For the lots being dosed at the 4-gram and 6-gram rates, treatment through Periods A and B involved treatment for 10 days after the cessation of mortality. In the lot being treated at the 4-gram rate through Periods A and B, mortality with *B. salmonicida* infection began again 13 days after the cessation of treatment, and continued at a low rate through Period D. In contrast, in the lot treated at the 6-gram rate there was only one death with known *B. salmonicida* infections (19 days after the cessation of treatment) together with two found free from the infection and two not checked.

It should be noted that the late fingerling dead were very small and thin, and that the large majority (65 percent) of those checked were infected with *B. salmonicida.* The small number spot checked for *Octomitus salmonis* were also found infected with this parasite.

At the close of the experiment, in order to check on the presence of fish serving as carriers, five of the largest and five of the smallest fish were removed from each trough and examined bacteriologically for the presence of *B. salmonicida.* Except for the controls, where none such remained, the smallest fish generally were notably thin and small. From Table 5, it may be seen that all of the carriers or late infections found were undersized fish.

TABLE 5.—*Dosage of sulfamerazine, brook trout fingerlings; testing for carriers of* Bacterium salmonicida

Numbers of trout	Dosage (in grams) per 100 pounds of fish per day, and size of fish							
	0[1]		2		4		6	
	Large	Small	Large	Small	Large	Small	Large	Small
Tested . . .	17	13	15	15	15	15	15	14
Carriers . .	0	0	0	1	0	2	0	2

[1] Controls

EFFECTS OF DOSAGE AND OF FREQUENCY AND DURATION OF TREATMENT

In the two experiments which formed the basis for this paper, three aspects of sulfamerazine dosage for furunculosis were involved: (1) the dosage rate; (2) the interval between doses; and (3) the duration of treatment.

In the first experiment, based on yearling brook trout, 4, 8, and 12 grams of sulfamerazine per day per 100 pounds of fish were effective, with 14.5-, 10.0- and 10.8-percent mortality, respectively, as compared with 59.5 percent in the untreated controls. (See also Table 1 and 2, Figs. 1 and 2). Evidently the 8-gram was as effective as the 12-gram rate, and the 4-gram not much less effective than the heavier dosage rates. In the second experiment, with fingerling brook trout, the daily dosage rates tried were 2, 4, and 6 grams per 100 pounds of fish. The corresponding mortalities were 94.0 (untreated controls), 64.4, 40.1, and 39.1 percent. (See also Tables 3 and 4, and Figs. 3 and 4).

It is evident that the 2-gram rate, although very helpful, was too light.

Between the 4-gram and 6-gram rates, the difference in effectiveness was small. The chief advantage for the 6-gram dosage rate lay in the earlier and sharper break in the mortality rate, and the almost complete elimination of the disease following treatment through Periods A and B. Because of these superiorities in results, and to be on the safe side, we favor the 6-gram rate.

The comparison of 8-hour and 24-hour intervals, between administrations of the drug, was inconclusive. Mortality was appreciably lower among the fish given sulfamerazine and food at 8-hour intervals; but so was it also among those given only food at 8-hour intervals (controls). Apparently there is no considerable advantage in administering the drug at less than 24-hour intervals, at least for yearlings.

From the first dosage experiment it was apparent that treatment for 10 days after mortality ended is as effective as longer treatment, or very nearly so. From the second experiment it was clear that treatment at 6-gram or lower rates for 4 days after mortality stops is insufficient.

Where treatment at 4-gram or 6-gram rates was stopped when mortality dropped to zero, mortality from furunculosis reappeared within 8 days. Where treatment was resumed after a lapse of 12 days, mortality was checked after a moderate loss, but where treatment was not resumed until 25 days had elapsed, the secondary mortality was considerable.

Treatment for 10 days after mortality stopped did not quite eliminate the disease, even when treatment was at the 6-gram rate (one fish dead with furunculosis, two dead without furunculosis, and two not checked), but the fact that the dead were undersized fish must be considered.

It has been noted that, late in the second experiment, the mortality with furunculosis was particularly heavy among the undersized fish. Moreover, all the fish found, by bacteriological examination at the close of the experiment, to be carriers or late infections were small. According to spot checks, the undersized fish were also infected with *Octomitus salmonis*.

These findings might explain why the cure of the fingerlings was less complete than the cure of the yearling brook trout. They indicate that the removal of all unduly small and thin fish early in the treatment is very desirable. Indeed, it may well be that such action, where such fish are present, is essential to the elimination of furunculosis.

Another practice, which might make the treatment more effective, is the prompt removal of all dead and dying fish. Such fish, because they are much nipped by the others, especially at feeding time, doubtless are an important factor in the spread of infection.

RECOMMENDATIONS

1. Remove all thin stunted fish as soon as they can be detected.
2. Keep pools or troughs clean.
3. Remove all dead fish several times a day.
4. Mix the sulfamerazine very thoroughly with food of good cohesion. Good practice is to mix sulfamerazine with dry feed (containing 4 percent of salt) before that is mixed with spleen and water. A satisfactory ratio of meat, dry feed, and water is 2:2:1, by weight.
5. During the period of treatment, give no food that does not contain sulfamerazine.
6. Give plenty of food—about all the fish will take, but not more.
7. Treat at the daily rate of 6 grams of sulfamerazine per 100 pounds of fish (13.2 grams per 100 kilograms).
8. Continue treatment through 10 days after mortality stops and through a total period of at least 3 weeks.
9. Observe strictly all sanitary measures practiced in the control of infectious diseases.

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THE EASTERN BELTED KINGFISHER, *MEGACERYLE ALCYON ALCYON* (LINNAEUS), IN RELATION TO FISH MANAGEMENT[1]

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Abstract

The kingfisher is the most common and universally distributed bird predator of fish in Michigan. Its principal migration routes are along the Great Lakes shores. Nesting territories are established along streams and lake shores; they are usually larger in the former than in the latter. The kingfisher is diurnal in its feeding with three peaks of activity—morning, afternoon, and early evening. First feeding of fledgelings is on insects; this food is followed by crayfish, then by fish. Fish eaten average about 2.3 inches in length and at fish hatcheries are mostly the species being propagated. On natural waters the food consists mostly of non-food and non-game fishes and crayfish. Predation pressure varies with season and within season according to weather, nest distribution, and environmental suitabliity of waters for feeding activity. Because of their feeding proclivities, it is undesirable to have kingfishers about fish hatcheries and rearing stations. At present, general control on natural waters is not biologically justified.

Introduction

This report is one of a series dealing with the relationships between fish predators and fish production. The purpose of this particular study has been to determine the relation between the eastern belted kingfisher and the production, artificial or natural, of food, game, and forage fishes. It has thus been necessary to determine the nature and extent of fish predation by this bird on natural waters and at outdoor fish hatcheries and rearing stations. As it became increasingly apparent that substantial losses of highly valued fish could result from the feeding activities of this predator at such stations, non-lethal controls were designed and tried (Lagler, 1939).

Our data are of two kinds: field observations of habits of kingfishers and the nature of fish populations; laboratory analyses of stomach contents. One or the other of the authors has devoted some time to this study each year from 1930 to 1945 and field observations and collections have been made in Michigan during all months.

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[1] Contribution from the Department of Zoology of the University of Michigan, and from the Institute for Fisheries Research of the Michigan Department of Conservation. Substantial financial aid was given this study by the Wildlife Management Institute (American Wildlife Institute) and by the Associated Fishing Tackle Manufacturers.

Most of the birds used for food analyses from fish-cultural establishments were obtained by employees of the Michigan Department of Conservation who followed instructions issued by us for the care and preservation of this material. Many other individuals, including colleagues in the Institute for Fisheries Research, collected specimens for us from natural waters.

We extend our sincere gratitude to the many persons and agencies that have helped us. Special thanks are due to Carl L. Hubbs, Fred A. Westerman, A. S. Hazzard, J. W. Leonard, and Karl E. Goellner. Ralph Hile read the manuscript and offered many critical suggestions for its improvement.

FIELD OBSERVATIONS

Since the emphasis of this paper is on the relationship of the food habits of the kingfisher to practical fishery management, we are presenting no lengthy discussion of life history which has been summarized by Bent (1940). Included only are apparently new materials based upon actual field observations and certain detailed information which will supply greater detail on activities of the bird which are generalized in other, previous accounts. Salyer is responsible for the field observations and their interpretation in the sections on distribution and migration, mating and nesting, and populations. Of all the observations recorded in the past on this species, those made by Gould[2] appear to be the most accurate. In fact, this painstaking study well merits publication even at this late date (*vide* Lagler, 1943).

Distribution and Migration.—Of all the winged fish predators of Michigan waters, the kingfisher is probably the most widely distributed. The species is principally a summer resident in Michigan but occasional individuals may be seen all winter long. The fact that this is a peninsular state with most of its boundaries on the shores of the Great Lakes has a profound influence on the migration and distribution of the kingfisher in the region. The first thing that strikes the observer who works daily in the field throughout the spring and summer months is the fact that travel is not haphazard or "cross-country" as stated by many writers. In short, in both the Upper and Lower Peninsulas, the shores of the Great Lakes are basic migration highways for the birds' movement.

Kingfishers pass up the shores of the Great Lakes in almost the same manner and regularity that native hawks exhibit in their migrations. On April 12, 1931, Salyer observed individual kingfishers moving along the west shore of Lake Huron north of the city of Port Huron at the rate of about 15 per hour during a 4-hour period in the morning. In the fall of the same year he found kingfishers moving southward on the shores of Lake Michigan at the mouth of the Pentwater River at the rate of 12 per hour. This observation was made on October 25; previous to this date Salyer had spent 3 days on the headwaters of the Pere Marquette River and had seen only one kingfisher there. It seems to the observer that on spring migration, kingfishers move along the Great Lakes shores and turn up major river valleys which they folow, dropping off as they locate, or return to, both new and old nesting sites.

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[2] Gould, Victor Eugene. 1934. "A monograph of the belted kingfisher *Megaceryle alcyon* (Linnaeus)", 311 pages plus illustrations, summary, and bibliography. Typewritten.

Mating and Nesting.—The female is slightly the larger, usually weighing a little more than 6 ounces, whereas the male averages a little less than 6 ounces. Observations by Salyer indicate that the female is the more aggressive of a nesting pair and takes the initiative in selecting the nesting territory. On the Huron River in Washtenaw County, the Platte River in Benzie County, and the Little Manistee River in Lake County, females have been found activly defending sites prior to getting a mate.

A mated pair of birds not only has a definite nesting territory, which they defend against all other individuals with fury and persistence, but their territory can be marked almost to the exact yard by the observer because of the behavior of the birds, described below.

A great amount of time in early mating season is spent by the mated pair in traversing and defending their territory. During the daylight hours at least, most of the territory appears to be patrolled at intervals of 10 to 15 minutes. All larger animals, including man, cats, dogs, and larger birds are circled and scolded and often followed through the area. Invaders of the same species are violently set upon forthwith.

The size of the nesting territories located on lakes contrasts sharply with that of sites on most streams or rivers. On lakes the longest territorial selection found was 1½ miles of shore, but the average comprises about ½ mile. This 1½-mile territory was occupied by a nesting pair of kingfishers on Black Lake, Cheboygan County, in June and July 1931. On the other hand, two nesting pairs used about ½ mile each of shoreline on Pleasant Lake, Washtenaw County, in May 1931. Another pair, during the same period, selected about ½ mile of shoreline of Portage Lake, Livingston and Washtenaw Counties, which included an extensive cottage area. The stretch of shoreline selected invariably includes all or a portion of a small sheltered bay which provides a reasonable extent of unruffled feeding surface regardless of most directions of the wind. Our studies indicate that exposure to wind action, especially on the lake habitat of the species, is almost as important as turbidity in determining the distribution of the population and the location and success of feeding. In this respect, it is significant to note that there are more kingfishers per unit of shoreline on the smaller Michigan lakes than upon such large, rough bodies of water as Houghton, Hubbard, and Mullet Lakes.

Limitations of feeding area on rivers by vegetative cover, deep and unfishable pools, and fast currents which reduce visibility, apparently require the birds to establish much larger territories. Thus, the usual range is most likely to be from 1½ to 3 miles or more. In May and June

1931, Salyer kept under close observation a pair of birds known to dominate the headwater country of the Little Manistee River for a distance of 6 miles. Although these birds were not marked, they appeared to be the only pair of kingfishers along this entire stretch of river. Their nesting hole was found and the feeding habits both of the adults and the young after leaving the nest were followed daily. Here the extensive "brushing-over" of long sections of the stream and the fast current seemed to limit feeding opportunities.

On the lower reaches of some of Michigan's larger rivers which are ordinarily quite turbid, the bird is an infrequent nester; however, all adjacent sloughs and backwater areas with relatively clear water have their nesting birds so that the nesting population of the entire state is of a somewhat uniform density.

In May 1931 Salyer made some interesting observations on a female bird which had selected a territory on a Huron River cutoff a few miles southeast of Ann Arbor, Michigan. This female actively defended the region for 2 days and took a mate on the afternoon of the second day. By the morning of the third day the male bird seemed to become familiar with the territory originally defended by the female. This male (K-318) was collected at 9:00 a.m. on the third day but by 3:00 p.m. on the same day there had appeared a new male bird which also learned the territory in a short time. The territory was composed of two small ponded areas estimated over-all at about 35 acres of water and marsh.

During the early mating season it is common to see and hear male kingfishers flying at altitudes of about 300 feet up this river valley. At regular intervals the migrant gives his characteristic rattling call. If a determined and vigorous challenge is returned by a prior occupant from below, he frequently passes on without stopping. Failing to get a challenge, the bird is often seen to go into a spectacular aerial dive and fly at a lower level. Sometimes he meets a female; if she already has a mate, she drives him away but if not, she may accept him. In any given watershed there always seem to be one or two bachelor birds which have not mated and which give the mated pairs considerable concern, especially in the early morning hours, as evidenced by repeated observations followed by collections.

Feeding Habits.—As is generally known, the kingfisher is a very adept fisherman, but its fishing is confined to those individuals of its prey near the surface or in shoal water. It apparently prefers to feed in the shallow waters of streams or lakes. In lotic habitats, fishing success is not as good in deep pools as it is in shallower reaches having a moderate to slow current.

The kingfisher is strictly a diurnal bird; it speedily retires with the advent of twilight in the evening. On the other hand, it is an early bird on the stream, becoming active in the early light before sunrise. The first hour of daylight is spent in feeding and repeatedly patrolling the territory during the nesting period.

Peaks of feeding activity occur in the morning, afternoon, and evening. Stomachs of birds taken very early in the morning prior to 7:00 a.m. are most often quite empty or contain a single recently taken item. Full stomachs are found more frequently in birds collected from 7:00 to 10:30 a.m. From about 11:00 a.m. to 2:30 p.m. apparently is largely a non-feeding period, with stomachs collected between 2:30 and 4:30 p.m. again being relatively full. Stomachs taken from around 4:30 to 6:30 p.m. generally show bone remains and seemingly the birds make their final feeding of the day just prior to dusk.

The first food which the young get when they leave the nest and start feeding without parental aid is insects, particularly mayflies. They are very fat when they first fly; this good condition is apparently necessary because the parents give the young birds little food just prior to the departure, perhaps to compel them to begin seeking food for themselves. Several broods have been watched by Salyer throughout the first and second weeks of their lives after they left their nests. In general, the family remains together for 10 to 15 days. During the first 3 or 4 days the young catch only flying insects from advantageous perches near the water, the parents generally perch on dead trees or exposed branches and the young on nearby dogwood, alder, or other shrubs where they are somewhat hidden. From these protected vantage points they fly out and seize a passing mayfly or caddisfly in a characteristic fly-catcher manner. All of the young of a brood taken on July 4, 1941, on the Black River (Montmorency County) on their first day on wing were feeding on insects. Several other broods and individual young showed the same habit. The young can be readily identified as such by their tarsal nesting callosities which gradually disappear toward the end of the third week on the wing (determined by field collections of birds of known age by Salyer).

During this period the young can be approached and observed quite closely despite the frantic warnings of the parents. The cries of the parents seem to rally the flock together and to keep it concentrated generally within a 100-yard stretch along the margin of the water area. It is most amusing to see both cedar waxwings and young kingfishers feeding on flying insects along northern trout streams in an almost identical manner.

After learning to catch insects, the young devote the fifth to tenth day on the wing almost exclusively to learning to capture crayfish. Broods in this period show a striking uniformity of behavior. For example, J. R. Greeley collected practically all of a brood on the Big South Branch of the Pere Marquette River (in Mason and Newaygo Counties) in the period from July 23 to July 28, 1931. All of these birds were feeding wholly on *Cambarus*. Again, Greeley collected a brood of young on August 14, 1931, on the same stream, of which all had fed upon crayfish while the male parent, also collected, was feeding normally upon fish; its stomach contained a 4-inch redhorse (*Moxostoma* sp.). This transitional crayfish-eating habit is substantiated by the stomach contents of individual young birds from several other points throughout the state. Thus, the kingfisher does not ordinarily begin to catch fish until the latter part of its second week on the wing. Two juvenile males and a juvenile female, collected at 7:30 a.m. on June 25, 1931, all had caught trout; they were then 18 days on the wing.

During the latter portion of the crayfish-feeding period, the family group is not as closely knit as previously and gradually disperses; the parents finally disappear and the young expand their feeding areas. The young, however, continue for a time to feed in the same general region in which their nest was located. They are usually found feeding first at intervals of ¼ to ½ mile from the nesting site and at greater distances in late August and September.

The writers have not spent much time studying the life of the kingfisher in the nest as this has been well covered by other authors. It was obvious, however, from the observations we made, that we could not accurately assay the food of nestlings by examining remains in the nests since females were repeatedly seen during the day to carry off a bolus or pellet of waste or undigested food remains from the nest. Because of the great quantities of food required daily to sustain the nestlings, the parents must, of necessity, remove the waste or the nest soon would become so congested with this material as to leave no room for either adults or young. We have not substantiated the observations of White (1939) that the young digest bones totally whereas the adults regurgitate the heavier bone material. It appears to us rather that in the initial period of feeding the nestlings, the parents present them with smaller and more delicate fish which disintegrate easily . Adults seem capable of digesting bone for in the stomachs we have examined both partially dissolved as well as fragmented bone have appeared. Thus, we hold, there is evidence of erosion and absorption in contradiction to the findings of White (1939).

It is our opinion that digestion in a kingfisher takes place more rapidly than in any other of the bird predators of Michigan fishes. The stomachs of kingfishers shot by us while they were feeding in their natural habitat are almost invariably either full of largely undigested food or contain only the traces of the last meal. One does not often get intermediate stages of digestion as in the case of the herons of which we have examined many specimens.

The total length of all fish eaten by kingfishers in Michigan averages less than 3 inches and ranges from 1 to 7 inches (Table 1). The minimum and maximum lengths were encountered only once each in the 729 specimens for which actual measurements or estimates based on comparative material were available. Most of the lengths determined were less than 5 inches; it is likely that fish of greater length are swallowed with difficulty. Individuals have been seen carrying fish in the 6- to 7-inch size group and sometimes have been observed to drop or abandon them. Fish which are intentionally or accidentally dropped by kingfishers show distintive marks on each side from the pincer action of the bill (as also noted by White, 1936). Often these marks are numerous on larger fish and bear evidence of manipulation in the unsuccessful effort to hold or swallow; we have several trout about 6 inches long in our collection which have these marks. The typical habit of attack and subsequent ingestion is for the bird to grasp a prey fish, forceps-fashion, with a lightning-like thrust aimed a little ahead of the middle of the body, fly to a perch, gradually turn the fish, and swallow it head first. Crayfish are taken similarly but are turned to pass down the esophagus tail first. Most of the whole or nearly whole fish and crayfish taken from stomach or esophagus are found headed in the directions indicated and are marked as described. The kingfisher does not spear or puncture larger prey with the closed bill as the great blue heron frequently does.

The kingfisher has been accused of taking nestling birds; we have never seen this nor do our food analyses give evidence of it.

Populations.—In the opinion of Salyer, the abundance of kingfishers on Michigan trout streams appears to parallel the striking increase of beaver population of the state in the decade prior to 1934. Beaver ponds opened up long reaches of the streams previously sheltered from kingfisher activities by overhanging trees and shrubs. There was a steady increment in the kingfisher population per stream unit on the Gladwin Game Refuge, which grew in proportion to the increased area flooded by the activities of the ever growing beaver population. In the summer of 1931 there was apparently only one kingfisher on 6 miles of the Jordan River (Charlevoix and Antrim Counties). In 1934, when Salyer was working in the same region again on beaver-trout investigations, 15 kingfishers were found in the same stretch of stream.

The relative richness of individual water courses also has a direct bearing on the number of kingfishers and other fish predators. For example, the Big South Branch of the Pere Marquette had by far a larger population of predatory birds, including kingfishers, than did the main stream. J. R. Greeley, in making a 14-mile float of 7 hours' duration down the Big South Branch, saw at least 12 individual kingfishers. Such rich streams as the Platte River (Benzie County) have a relatively heavy population of kingfishers in comparison with a poorer stream such as the Boardman River (Grand Traverse County). Such contrasts are repeated many times over the state. For the suitable portions of the Northeast Margaree and its tributaries in Nova Scotia, White (1936) estimated one kingfisher nest per mile with a minimum of seven birds ultimately feeding from each nest.

Predation Pressure.—Predation by kingfishers on natural waters is different in quality and quantity in the different ecological situations represented in the state and it varies in all situations with the weather and seasons. The pressure reaches its low during winter months when only a few birds are in the region. During this time the lakes are usually ice-covered and feeding routes are along streams that do not freeze over. These are, for the most part, trout streams in the Lower Peninsula but winter-resident kingfishers are so few that no concern need be felt over them even though they are restricted as to the waters that they frequent. In the spring, summer, and fall, kingfishers have been observed feeding in almost all kinds of waters, both inland and along the margins of the Great Lakes. They are strikingly absent from feeder or nursery portions of stream systems, both trout and non-trout, where the marginal vegetation more or less covers the water, often forming a complete canopy from one to a few feet above it. Examples of the latter situation are the alder-covered sections of the Maple River near Pellston, Emmet County, and of the Hurricane River near Ausable Point, Alger County. Feeding birds are not seen along the turbid, lower reaches of the larger rivers, especially in the southern part of the Lower Peninsula, such as those of the Grand, Kalamazoo, Huron, and Raisin Rivers. Birds are characteristically absent from places that they ordinarily frequent along waterways when these are temporarily muddied by run-off immediately following heavy rains. They furthermore retreat from the Great Lakes shores when surf makes the water there unfishable. It may be presumed that during both of the latter conditions, recourse is had to tributaries or to other sheltered clear waters which then experience a temporary increase in the predation pressure. Trautman (1940) has described the utilization of tributaries for feeding grounds by migrants at Buckeye Lake, Ohio, when the main body of water is iced-over or turbid. On most waters the predation pressure is greatest in late summer and early fall, when, as a result of the flight of the young, the total effect is increased; but most "buffer," forage fishes have reproduced and temporarily increased their numbers by this time so that the relative effective pressure on game species by the predators may actually be less. The average increase in daily numbers of birds seen in a given locality from spring to fall may be fourfold as indicated by Trautman (1940).

Food Studies

Specimens for food study are from a wide range over the state (Figs. 1 and 2) but only a sample randomly selected from each locality is reported here since experience has shown that the numbers used are adequate and that inclusion of additional ones discloses insignificantly few new facts. The methods employed in the laboratory for stomach-content analyses, which were as precise as possible both qualitatively and quantitatively, follow those described by Salyer and Lagler (1940). We did not study regurgitated pellets such as those which formed the basis of White's (1937) work. All quantitative results, except those for lengths of fishes at capture (Table 1), are thus based on actual counts and measurements. Fragmentary remains of fish were most often found; in order to obtain information on sizes of fish eaten, it was therefore usually necessary to estimate the former whole lengths from fragments. This estimation was made by comparison of remaining parts with entire specimens or with skeletons of fish of the same kind and of known length.

TABLE 1.—*Total length (inches) of fishes eaten by the eastern belted kingfisher*

Kind of fish	Minimum length	Average length	Maximum length	Number of individuals
Trouts	1.0	2.3	7.0	651
Suckers	2.7	3.4	4.0	2
Minnows	1.5	2.3	4.0	6
Bullhead	3.5	3.5	3.5	1
Northern pike .	4.7	4.7	4.7	1
Topminnows ...	1.5	1.8	2.0	2
Mudminnows ...	1.5	3.0	5.0	6
Yellow perch ...	1.8	3.1	4.5	3
Black basses ...	1.8	3.0	5.0	17
Sunfishes	1.8	2.6	4.0	15
Muddlers	1.7	2.7	4.0	14
Sticklebacks ...	1.5	1.8	2.3	11

Kingfishers collected by shooting, if they contain any bony fragments of food at all, usually have in them certain remains which are identifiable as to kind of organism. The stomachs of birds taken in pole traps are practically worthless in food analyses. Trapped individuals make frantic struggles to escape with the result that the food is regurgitated and lost or, if the trap is not so situated that the bird is plunged into water and drowned, food materials which remain in the stomach are very rapidly digested. Furthermore, a strategically located trap will almost invariably take a kingfisher before he has fed at the particular site.

Kingfishers at Fish Hatcheries.—It has long been known that kingfishers feed upon fishes in ponds and raceways at fish-cultural establishments. Some observations on predation and many complaints about losses to predators at such stations have been recorded. For example, in 14 kingfishers that had eaten mostly crayfishes and aquatic insects from an Ohio fish farm, Langlois (1936) found two smallmouth bass in only one bird. He suggested that this species might be more destructive than the wading birds later in the season when the bass are larger and faster and do not spend so much of their time in the shallows. De la Torre Bueno (1936) reported taking reared trout from the stomachs of hatchery kingfishers and added that this bird offers the most serious threat when the young first leave the nests and fly to rearing ponds with the adults in family groups of four to six birds. He concluded that three fingerling trout constitute a day's ration for a kingfisher. The remedy suggested as best was screening of the ponds. Hoover (1936) found 16 brook trout ranging from 1.5 to 5.5 inches in length in the stomachs of nine kingfishers taken at hatcheries in New Hampshire and concluded that the exact status of this bird is in need of study and that until such investigation is completed, reasonable control is necessary.

The fish rearing stations in Michigan, where predation by kingfishers occurs, are of two kinds; pondfish hatcheries, usually used for centrarchids, in the southern part of the Lower Peninsula; trout rearing stations mostly in the northern part of the Lower Peninsula and in the Upper Peninsula (Fig. 1).

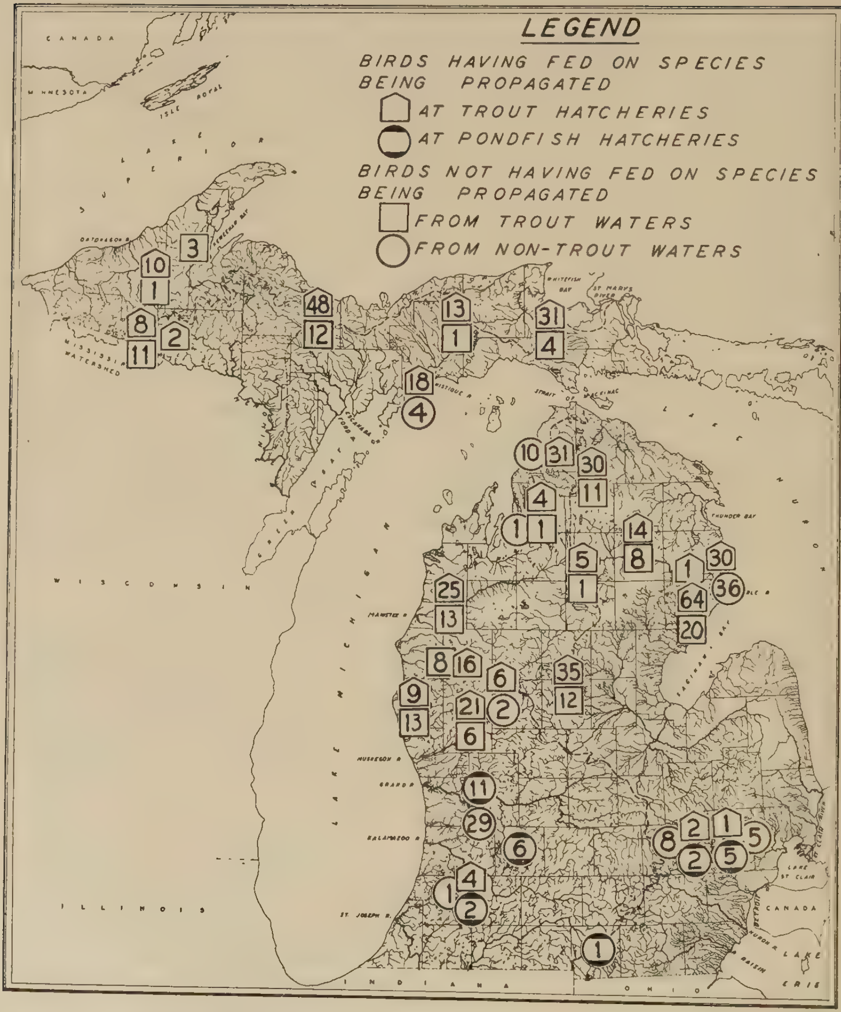
LEGEND
BIRDS HAVING FED ON SPECIES BEING PROPAGATED
AT TROUT HATCHERIES
AT PONDFISH HATCHERIES
BIRDS NOT HAVING FED ON SPECIES BEING PROPAGATED
FROM TROUT WATERS
FROM NON-TROUT WATERS
CANADA
MINNESOTA
ISLE ROYALE
LAKE SUPERIOR
MISSISSIPPI WATERSHED
WHITEFISH BAY
ST MARYS RIVER
STRAIT OF MACKINAC
THUNDER BAY
WISCONSIN
LAKE MICHIGAN
MANISTEE R
MUSKEGON R
GRAND R
KALAMAZOO R
ST JOSEPH R
ILLINOIS
INDIANA
OHIO
LAKE ST CLAIR
CANADA
LAKE ERIE
3
10
1
8
2
11
48
12
13
1
31
4
18
4
10
31
30
4
11
1
1
14
8
5
1
30
1
36
64
20
25
13
8
16
6
35
9
21
2
12
13
6
11
29
6
8
2
1
5
2
5
4
1
2
1

FIGURE 1.—Distribution, numbers, and classification of kingfishers collected at fish-cultural stations in Michigan and studied for food.

In a general way, these two types of fish-cultural establishments represent distinct ecological entities in that the waters of pondfish stations are impoundments (often sizable: one of several near Almena, Van Buren County, is about 38 acres) whereas those of trout rearing establishments are small, stream-like raceways with moderate current and either of artificial construction near springs or sections of natural waters set off

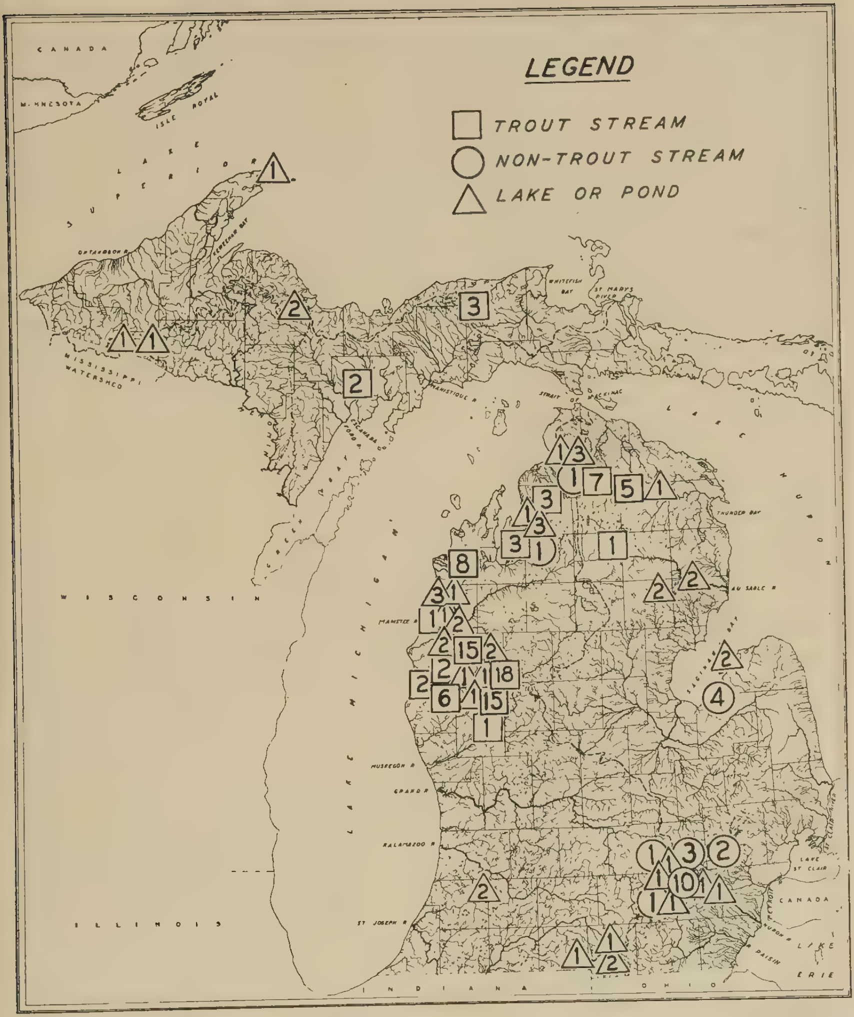
LEGEND
TROUT STREAM
NON-TROUT STREAM
LAKE OR POND
CANADA
MINNESOTA
ISLE ROYALE
LAKE SUPERIOR
MISSISSIPPI WATERSHED
WHITEFISH BAY
ST MARYS RIVER
STRAIT OF MACKINAC
THUNDER BAY
AU SABLE R
MANISTEE R
MUSKEGON R
GRAND R
KALAMAZOO R
ST JOSEPH R
WISCONSIN
ILLINOIS
INDIANA
OHIO
LAKE ST CLAIR
CANADA
LAKE ERIE

Figure 2.—Distribution, numbers, and ecological classification of habitat for kingfishers collected on natural waters in Michigan. No birds shown in Figure 1 are repeated here.

by low dams or screens. Both types are alike, however, in containing greater concentrations of fishes of the size particularly desirable to kingfishers than exist in similar areas of natural waters. Both also appear to attract more kingfishers per unit area than do natural waters. Once an individual discovers this great and apparently inexhaustible food supply of an ideal size, it will come back to feed again and again so that it is almost necessary to kill the bird in order to stop its depredations—especially if it has young nearby requiring repeated feedings and a large quantity of food.

It is common practice to kill kingfishers as a means of controlling their depredations at fish hatcheries, rearing stations, or holding ponds. It would seem that the huge take of kingfishers at the various hatchery sites in Michigan and elsewhere in the last 15 years could ultimately be responsible for a reduction in their numbers. A serious downward trend resulting from this cause could be arrested in part by a more sane and understanding handling of the bird's predatory activities. The critical period for protecting fish hatcheries and feeding stations is the month of May and the first half of June. At that time the birds are seeking territories and nesting. If they once locate the huge supply of food organisms in the hatchery ponds, of exactly the length they require, it is almost impossible to drive them away. However, if the hatchery force is alert and has guns at strategic points about the hatchery grounds during this interval, and if the bird is fired at when it first apears, even if there is no hope of hitting it, usually it will take the hint and seek a more congenial habitat. These early birds seeking territory make themselves most conspicuous by constantly uttering their shrill, rattling, challenge call.

As a means of control, it is important that no poles or other supports 4 feet or more in height be permitted in the vicinity of the ponds; they greatly facilitate activity of kingfishers since they provide excellent fishing and observation perches and thus may even attract the birds. The general use of pole traps is to be discouraged since so many song birds are taken by them. Scarecrows, flashing lights, or mirrors, and even automatic detonators are only temporarily effective since kingfishers appear to become accustomed to them and have been seen to fish from the structures supporting such devices. Screening is the most effective means of control and is most desirable esthetically but it is limited in its application to smaller bodies of water and is by no means adapted to maximum efficiency in hatchery practice (see Lagler, 1939, for description of various types of screening).

Some foresight in locating fish hatcheries and rearing stations may be valuable in reducing depredations by certain bird species including the kingfisher. Because of the great numbers of migrating kingfishers along the shores of the Great Lakes, it would be sheer folly in the future to locate any new hatchery or feeding station within 5 miles of lake shores since such a location would be directly athwart the flight lanes of the birds (and of herons and mergansers as well). The Harrisville Hatchery (Alcona County) near the shore of Lake Huron is a case in point. Predation by kingfishers always has been heavy there and is a constant problem. This problem is even more accentuated at a private hatchery near the Lake Michigan shore. The owners of this hatchery told us that they shot and trapped more than 400 kingfishers in one spring migration.

In the spring of 1931 there was to be seen on the grounds of this hatchery a dump of more than several bushels of kingfisher bodies. This deplorable situation can be eliminated by future planning.

Conversion of sections of headwater streams into rearing stations may invite kingfisher depredation. The opening produced in the streamside shrubbery by the creation of extended pools would tend to attract and concentrate the activities of fish-eating birds.

Trout Rearing Waters.—Of the many kingfishers studied by us from waters of this type, 428 contained food and many additional ones were empty. The stations where these specimens were obtained and the number with food from each are shown in Figure 1. The principal food of birds at these places were the salmonids being propagated (Table 2) since they comprised 80.1 percent of the total volume of food and averaged two per bird. Other prominent items eaten in decreasing numerical order were aquatic insects, forage fishes (mostly minnows, muddlers, and sticklebacks), and crayfishes.

Table 2.—*Food of the eastern belted kingfisher on trout rearing waters*

[Based on the stomach contents (747.8 cubic centimeters of food) of 428 individuals[1]]

Food item	Number of individuals of each food item	Percentage of total volume of food	Percentage frequency of occurrence
Trout	981	80.1	100.0
Other game and pan fishes..	11	2.1	1.0
Forage fishes	163	3.7	21.0
Fish remains	...	2.5	10.3
Amphibians	9	1.8	1.6
Other vertebrates	2	0.5	0.5
Crayfishes	62	7.3	14.3
Insects	347	3.2	24.1

[1] Detailed identifications and enumerations of the food items in these birds follow. Trout: *Salmo gairdnerii irideus,* 2; *S. trutta fario,* 2; *Salmo* sp., 54; *Salvelinus f. fontinalis,* 213; Salmonidae, 710. Other Game and Pan Fishes: Percidae, 2; *Lepomis cyanellus,* 2; *L. gibbosus,* 1; *L. m. macrochirus,* 1; Centrarchidae, 5. Forage Fishes: *Catostomus c. commersonnii,* 2; Catostomidae, 1; *Rhinichthys atratulus meleagris,* 1; *Semotilus a. atromaculatus,* 1; *Margariscus margarita nachtriebi,* 1; *Hyborhynchus notatus,* 4; *Notemigonus crysoleucas auratus,* 1; *Notropis cornutus,* 2; Cyprinidae, 12; *Umbra limi,* 4; *Fundulus diaphanus menona,* 1; Etheostomatinae, 5; *Cottus,* 99; *Eucalia inconstans,* 31. Amphibians: salamanders, 2; frogs, 7. Other Vertebrates: mice, 2. Crayfishes: *Cambarus virilis,* 1; *C. immunis,* 1; *C. propinquus,* 12; *Cambarus* sp., 48. Insects: Orthoptera, 1; Baetinae, 27; Ephemeridae, 10; *Libellula,* 1; *Anax junius,* 1; *Aeschna umbrosa,* 2; Zygoptera, 4; Anisoptera nymphs, 17; Odonata, 5; Plecoptera, 1; *Lethocerus americanus,* 1; Belostomatidae, 2; Aphidae, 1; *Helicopsyche,* 4; Trichoptera, 80 ;*Dytiscus,* 1; Dytiscidae, 2; Carabidae, 1; Staphylinidae, 3; Chrysomelidae, 1; Coleoptera, 29; Chironomidae, 99; Stratiomyidae, 1; Rhagionidae, 1; Diptera, 4; Formicidae, 1; Hymenoptera, 8; unidentified, 42.

Some of the food appearing in the stomachs of these birds obviously had been eaten prior to their descent upon the hatchery waters. This view is substantiated by the considerable number of individuals (131) taken at these stations but not containing representatives of the species being propagated (Fig. 1). Such birds, it seems, were killed before they had opportunity to prey on fishes in the rearing enclosures and for this reason they are discussed with kingfishers from natural trout streams (Table 4). It is likewise possible that some of the kingfishers collected at the hatcheries and containing trout may have obtained those fish from the adjacent natural waters. Since we had no way of detecting these trout from natural waters for most birds and in view of the much lower incidence of trout in the food of this bird on natural trout waters (Table 4) we believe the inherent error to be insignificant. Furthermore, trout hatcheries using spring water, such as the one near Almena, Van Buren County, or that at Oden, Emmet County, have practically no trout streams nearby and the birds entering would therefore not be likely to contain such fishes.

Pondfish Rearing Waters.—Twenty-seven kingfishers are available for recording the food habits of this bird on such waters (Table 3). Several more that were opened were empty and still others contained none of the species being propagated. The latter birds taken at pondfish hatcheries are considered to have flown in from adjacent non-trout waters and are discussed with kingfishers from non-trout streams (Table 5).

TABLE 3.—*Food of the eastern belted kingfisher on pondfish rearing waters*
[Based on the stomach contents (59.1 cubic centimeters of food) of 27 individuals[1]]

Food item	Number of individuals of each food item	Percentage of total volume of food	Percentage frequency of occurrence
Pan fishes	52	85.8	100.0
Forage fishes	44	8.0	40.7
Fish remains	..	0.8	25.9
Crayfishes	6	2.7	18.5
Insects	14	2.7	29.6

[1] Detailed identifications and enumerations of the food items in these birds follow. GAME AND PAN FISHES: *Micropterus salmoides,* 1; *Micropterus d. dolomieu,* 9; black basses, 26; *Lepomis gibbosus,* 1; *L. m. macrochirus,* 7; Lepominae, 2; Centrarchidae, 6. FORAGE FISHES: Catostomidae, 2; *Notemigonus crysoleucas auratus,* 1; *Notropis cornutus,* 4; Cyprinidae, 11; *Umbra limi,* 1; *Cottus* sp., 8; *Eucalia inconstans,* 17. CRAYFISHES: *Cambarus virilis,* 1; *C. immunis,* 2; *Cambarus* sp., 3. INSECTS: Odonata, 4; Ephemeridae, 1; Coleoptera, 1; Chironomidae, 5; unidentified, 4.

The kingfisher at warm-water fish rearing establishments shows a striking resemblance (Table 3) in food habits to those from trout cultural stations (Table 2). The birds average about two per individual of the species being propagated and these fishes compose 85.8 percent of the total volume of food. The remainder of the organisms eaten are again principally minnows, crayfishes, and insects.

Kingfishers on Natural Waters.—The food habits of the kingfisher on natural waters have been summarizd by Bent (1940) with the indication that juveniles and adults feed on the most available aquatic organisms of suitable size. This general conclusion is attested by the following data from extensive analyses on record in the U. S. Fish and Wildlife Service (Howell, 1932). Perch, mainly *Perca flavescens,* were found in 16 stomachs; catfishes in 15; flounders in 13; sunfishes in 9; and carp in 3. Non-edible fishes were identified in 82 of 162 stomachs; small minnows were in 57, sculpins were in 8, and sticklebacks, killifishes, and menhaden made up the remainder. Crayfishes were present in 39 individuals, comprising about 16 percent of the food, frogs formed about 5 percent, and insects, 4 percent. Fishes in all composed about 75 percent of the food of the bird.

In an analysis of the food of kingfishers in various habitats progressively further upstream in the Margaree and Apple River systems of Nova Scotia, White (1937) found that in the lower reaches many species of fish are taken, but further upriver the number of kinds becomes less until only salmon and brook trout or trout alone constitute the food. In a more restricted region, though one possessing a diverse fauna, namely in the vicinity of Ithaca, New York, breadth of food habit is again indicated (Gould, MS).[3]

We have new data on the food of the kingfisher on trout streams, non-trout streams, and lakes (Fig. 2). Stomachs of this bird on natural waters are from two principal sources. One group is from bona fide natural situations and was collected over most of the state in order to obtain a general picture of the kinds and amounts of food eaten. The other represents a more or less chance accumulation of birds resulting from control operations at fish hatcheries and rearing stations (Fig. 1). Many birds shot or pole-trapped at fish-cultural stations contained none of the species being cultured and, as indicated, have not been previously reported upon in this paper. Data on these birds are presented separately in the tables for birds from trout streams (Table 4) and from non-trout streams (Table 5). Obviously these specimens taken at hatcheries offer significant information on predation at fish-propagation establishments but they appear to contribute more to an understanding of the food habits on natural waters. That such kingfishers represent individuals taken prior to feeding in the hatchery waters is substantiated by their stomach contents. The fact that these specimens were selected on the basis of the absence of the species being reared from their stomach contents precludes their being used in any way to indicate nonexistence of predation in natural waters on the fish species primarily concerned. They do afford, however, an amplification of the list of other organisms preyed upon by kingfishers and corroborate the evidence afforded by the bona fide samples from natural waters so well that additional sacrifice of birds for food study was unneccessary.

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[3] A condensation of Gould's original records of analyses, made by the U. S. Fish and Wildlife Service, is reproduced here with the permission of Harrison F. Lewis, in whose custody the manuscript lies, since it is likely that it will remain unpublished for some time. The name of each food item and the number of times the item occurred in the 25 stomachs examined are given. For the fishes, the list is in decreasing order of number of individuals of each item. Fish: *Pomolobus* sp., 5; *Salmo trutta fario,* 9; *Catostomus c. commersonnii,* 14; Cyprinidae, 12; *Cyprinus carpio,* 1; *Leucosomus corporalis,* 1; *Semotilus a. atromaculatus,* 15; *Exoglossum maxillingua,* 2; *Rhinichthys a. atratulus,* 7; *Hybopsis* sp., 2; *Hybognathus* sp., 1; *Notropis* sp., 4; *Notropis cornutus,* 9; *Ameiurus* sp., 4; *Fundulus diaphanus,* 1; *Perca flavescens,* 2; *Boleosoma nigrum,* 4; *Micropterus salmoides,* 5; *Lepomis* sp., 2; *Lepomis gibbosus,* 4; *Cottus* sp., 1. Frogs: *Rana* sp., 6. Reptiles: Snakes, 2. Insects: Anisoptera, 1; Aeschnidae, 1; *Hydrous triangularis,* 1; *Berosus* sp., 1; *Haliplus* sp., 1; Elateridae, 1; Chrysomelidae, 1; Curculionidae, 1; *Camponotus herculeanus,* 1; Hymenoptera, 1. Crustaceans: *Cambarus* sp., 19.

Trout Streams.—Trout streams of a wide variety of sizes and kinds are found in Michigan. As has been indicated, fishes in all except the smallest of them are exposed to predation by kingfishers. That trout are eaten cannot be denied; our findings (Table 4) show an incidence of approximately one for every two birds. Almost two-thirds of the bulk of the food and most of the food organisms by number, however, are made up of forage fishes and crayfishes. It is suspected that the vulnerability of forage fishes varies greatly from stream to stream. Furthermore, it is generally conceded that such fishes are less wary than trout and that they are most abundant in the open, sunlit parts of the streams (Hankinson, 1923) which kingfishers frequent whereas the trout are in

Table 4.—*Food of the eastern belted kingfisher on trout streams*

[Based on the stomach contents (266.7 cubic centimeters of food) of 92 individuals collected on natural trout streams[1] and on the stomach contents (186.1 cubic centimeters of food) of 131 individuals taken at fish hatcheries but representing food habits on natural trout waters[2]]

Food item		Number of individuals of each food item		Percentage of total volume of food		Percentage frequency of occurrence	
		From natural trout streams	From hatcheries	From natural trout streams	From hatcheries	From natural trout streams	From hatcheries
Game and pan fishes	Trout	40	. . .	29.8	. . .	35.9	. . .
	Others	14	14	13.0	4.4	13.0	6.9
Forage fishes		68	122	15.0	15.4	35.9	39.7
Fish remains		. .	. . .	0.9	0.9	14.1	9.2
Frogs		1	12	Trace	13.2	1.1	7.6
Crayfishes		58	56	40.7	50.5	53.3	39.7
Insects		8	91	0.6	15.5	8.7	34.4

[1] Detailed identifications and enumerations of the food items in birds collected on natural trout streams follow. Game and Pan Fishes: *Salmo gairdnerii irideus*, 6; *S. trutta fario*, 1; *Salmo* sp., 3; *Salvelinus f. fontinalis*, 5; Salmonidae, 25; Ameiuridae, 1; *Esox lucius*, 1; *Perca flavescens*, 5; *Lepomis m. macrochirus*, 2; Centrarchidae, 5. Forage Fishes: *Moxostoma* sp., 1; Catostomidae, 2; Cyprinidae, 6; *Umbra limi*, 1; Etheostomatinae, 5; *Cottus* sp., 22; *Eucalia inconstans*, 29. Frogs: *Rana* sp., 1. Crayfishes: *Cambarus virilis*, 14; *C. propinquus*, 20; *Cambarus* sp., 24. Insects: Anisoptera, 3; Stratiomyidae, 1; unidentified, 4.

[2] Detailed identification and enumerations of the food items in birds collected at hatcheries but representing food habits on natural trout waters follow. Game and Pan Fishes: *Perca flavescens*, 2; *Micropterus d. dolomieu*, 1; *Lepomis cyanellus*, 4; Centrarchidae, 7. Forage Fishes: *Catostomus c. commersonnii*, 2; Catostomidae, 3; *Rhinichthys atratulus meleagris*, 1; *Semotilus a. atromaculatus*, 2; *Hyborhynchus notatus*, 9; *Notropis cornutus*, 5; *Cyprinidae*, 24; *Umbra limi*, 1; *Fundulus diaphanus menona*, 7; Etheostomatinae, 5; *Cottus cognatus*, 1; *Cottus* sp., 34; *Eucalia inconstans*, 26. Frogs: *Rana* sp., 12. Crayfishes: *Cambarus virilis*, 3; *C. propinquus*, 24; *C. immunis*, 6; *C. diogenes*, 1; *Cambarus* sp., 22. Insects: Orthoptera, 1; *Anax junius*, 2; *Epiaeschna* sp., 1; Anisoptera nymphs, 19; Odonata, 1; *Lethocerus americanus*, 1; *Lethocerus* sp., 2; Belostomatidae, 2; Cicadellidae, 1; Aphidae, 1; Ephemeridae nymph, 1; *Dytiscus Harrisii*, 2; *Dytiscus dauricus*, 1; *Dytiscus* sp., 1; Dytiscidae, 15; Gyrinidae, 1; *Haliplus* sp., 1; Coleoptera, 1; Trichoptera larvae, 27; Diptera eggs, 6; unidentified, 2. One water mite, Acarina, was also found and is included in this category for convenience.

Table 5.—*Food of the eastern belted kingfisher on non-trout streams*

[Based on the stomach contents (67.7 cubic centimeters of food) of 22 individuals collected on natural waters[1] and on the stomach contents (157.8 cubic centimeters of food) of 95 individuals taken at fish hatcheries but representing food habits on natural waters[2]]

Food item	Number of individuals of each food item		Percentage of total volume of food		Percentage frequency of occurrence	
	From natural non-trout streams	From hatcheries	From natural non-trout streams	From hatcheries	From natural non-trout streams	From hatcheries
Game and pan fishes	5	7	10.5	3.4	22.7	6.3
Forage fishes	12	89	31.3	17.1	40.9	35.8
Other fishes	1	..	16.2	....	4.5	....
Fish remains	..	..	0.1	0.8	13.6	6.3
Frogs	..	6	...	9.7	...	2.1
Other vertebrates ...	..	2	...	1.3	...	2.1
Crayfishes	18	32	39.6	18.8	59.1	27.4
Insects	4	57	2.2	49.0	18.2	42.1

[1] Detailed identifications and enumerations of the food items in these birds follow. Game and Pan Fishes: *Perca flavescens,* 2; Centrarchidae, 3. Forage Fishes: Catostomidae, 1; *Hyborhynchus notatus,* 3; *Notemigonus crysoleucas auratus,* 1; *Notropis atherinoides,* 2; *N. hudsonius,* 1; Cyprinidae, 2; *Umbra limi,* 1; *Cottus* sp., 1. Other Fishes: *Esox vermiculatus,* 1. Crayfishes: *Cambarus propinquus,* 14; *Cambarus* sp., 4. Insects: Belostomatidae, 2; Ephemeridae, 2.

[2] Detailed identifications and enumerations of the food items in birds collected at hatcheries but representing food habits on natural non-trout waters follow. Game and Pan Fishes: *Perca flavescens,* 3; *Lepomis cyanellus,* 2; *L. m. macrochirus,* 2. Forage Fishes: *Catostomus C. Commersonnii,* 2; Catostomidae, 1; *Hyborhynchus notatus,* 12; *Notropis cornutus,* 50; Cyprinidae, 10; *Umbra limi,* 4; *Fundulus diaphanus menona,* 1; Etheostomatinae, 5; *Cottus b. bairdii,* 2; *Cottus* sp., 2. Frogs: *Rana* sp., 6. Other Vertebrates: Turtle egg, 1. Crayfshes: *Cambarus virilis,* 6; *C. propinquus,* 5; *C. immunis,* 7; *Cambarus* sp., 15. Insects: *Anax junius,* 4; Aeschnidae, 2; Anispotera nymphs, 11; *Lethocerus americanus,* 8; *Lethocerus* sp., 3; *Benacus* sp., 1; *Dytiscus harrisii,* 1; *Dytiscus* sp., 13; *Acilius* sp., 2; Dytiscidae, 2; Coleoptera, 1; Chironomidae larvae, 2; unidentified, 1.

the darker, deeper, and more sheltered portions. Experiments on the effects of predation by White (1937) led to the conclusion that competition and cannibalism were a greater menace to young trout than attacks by birds including kingfishers and members of the heron family.

A part of the food is composed of game and pan fishes other than trout, which have no recognizable value for sport in these situations. At least some of these fishes are strays from lakes situated in the drainage systems of the streams and are not regular inhabitants of Michigan trout waters. Some that are eaten, for example the predacious northern pike (*Esox lucius*), are liabilities in trout streams as indicated by Hankinson (1923). Crayfishes, forage fishes, and insects are utilized in common by trout (Metzelaar, 1929; Needham, 1938; Lagler and Lagler, 1944) and by kingfishers. It has further been suggested (Hankinson, 1923) that two of the forage species (*Semotilus a. atromaculatus* and *Notropis cornutus*) eaten by kingfishers may be incompatible with native trout since they offer competition for food.

The interrelationships of predator and prey are here, as always, very complicated, and the exact status of the kingfisher in relation to trout production in natural waters is therefore undecipherable on the basis of the data thus far obtained.

Non-trout Streams.—The considerable importance of crayfishes as seen in the food of kingfishers on trout streams (Table 4) is also somewhat evident in that of specimens from running waters that are not inhabited by trout (Table 5). To some extent the large numbers of crayfish may be the result of the numerical dominance of young birds in our collections. Insects are more important in birds collected at hatcheries, but not containing hatchery fish, than in those from natural waters. Forage fishes again are the numerically dominant food organisms and, among the fish, they exceed the others by far in both numbers and bulk. This preponderance of forage fish, of course, reflects the leading numerical abundance which is usual for forage species in fish populations in streams of this kind. Vertebrates as a whole appear to be of greater significance to the kingfisher as food on these waters than are the arthropods.

Lakes.—A difference in the food habits of kingfishers in standing waters from those in running waters is suggested by our data (Table 6). Crayfishes are not a food item of major importance to this bird in lacustrine situations. This fact would seem to indicate a lesser abundance of these decapods per unit area of fishable lentic waters than lotic ones, or it might suggest a greater proportionate abundance of forage fishes to crayfishes in the former since much of the numerical and volumetric loss for crayfishes has been gained by forage fishes which are by far the most important item of sustenance. Insects are second by volume in apparent importance but game and pan fishes are probably of greater actual significance for their volume would exceed that of the insects if both were

TABLE 6.—*Food of the eastern belted kingfisher on lakes*

[Based on the stomach contents (92.1 cubic centimeters of food) of 45 individuals[1]]

Food item	Number of individuals of each food item	Percentage of total volume of food	Percentage frequency of occurrence
Game and pan fishes	29	17.5	20.0
Forage fishes	78	49.1	51.1
Other fishes	2	2.0	4.4
Fish remains	..	0.9	22.2
Frogs	6	2.3	13.3
Crayfishes	18	7.4	26.7
Insects	15	21.0	37.8

[1] Detailed identifications and enumerations of the food items in these birds follow. GAME AND PAN FISHES: *Perca flavescens,* 17; *Micropterus d. dolomieu,* 1; *Lepomis cyanellus,* 1; *L. gibbosus,* 1; *L. m. macrochirus,* 3; Centrarchidae, 6. FORAGE FISHES: Catostomidae, 1: *Cyprinus carpio,* 1; *Hyborhynchus notatus,* 49: *Notemigonus crysoleucas auratus,* 1; *Notropis hudsonius,* 1: *Cyprinidae,* 7; *Umbra limi,* 1; *Percina caprodes semifasciata,* 1; Etheostomatinae. 7: *Labidesthes s. sicculus,* 7; *Cottus* sp., 1; *Eucalia inconstans,* 1. OTHER FISHES: Esocidae. 1; *Lota lota maculosa,* 1. FROGS: *Rana* sp., 6. CRAYFISHES: *Cambarus virilis,* 3; *C. immunis,* 1; *C. propinquus,* 3; *Cambarus* sp., 11. INSECTS: *Anax junius* nymph, 1; Anisoptera, 3; Belostomatidae, 1; Dytiscidae, 2; unidentified, 8.

restored to their original bulk on ingestion. The number of specimens of kingfishers on which these observations are based is, however, small.

PRESENT STATUS OF THE KINGFISHER PROBLEM

Several comments have been published on the relationships between fish-eating birds, including the kingfisher, and fish. Vladykov (1943) alone has attempted to present in one paper an unbiased summary of the views of the several authors and has listed the three categories of interpreters of the role of these birds. (1) ultra-preservationists; (2) exponents of stringent control; (3) those who take the middle course. In general one would find over-enthusiastic laymen or those directly dependent upon them for income in the first two categories, and, those who try to apply a more scientific method in arriving at their conclusions in the third. Obviously, then, our data constitute ammunition for any of these groups. Ultra-preservationists will emphasize the broad diet of the kingfisher, as here attested, and will continue against control. Fish-culturists and ardent anglers will regard as of primary importance the feeding of the bird on populations of their selected species. Neither group will, however, be fully able to justify its case on the basis of what is now known. Staggering and damning estimates of the total numbers of fish consumed may be made (*e.g.*, Sinker, 1883; Sullivan, 1912; White, 1936), but unless these estimates are interpreted in light of existing populations of both predators and prey in specific areas, they are obviously invalid and worse than misleading.

The conclusions that we draw from our study are very limited and not at all trenchant. Because of its predatory potential of more than 50 small fingerlings per day (determined experimentally by White, 1936) and the established fact that on fish rearing waters it consumes quantities of the fishes being propogated, the kingfisher is incompatible with fish-cultural practices of the present time. In recognition of this difficulty, may not organizations fostering the ultra-preservationist attitude be expected to share in the extra cost of protecting fishes at hatcheries by non-lethal means rather than by shotgun or pole-trap? On natural waters, with the possible exception of spawning areas or of nursery grounds such as headwater trout streams, we conclude that the kingfisher is relatively innocuous as a fish predator. Such prey in the form of preferred fish species or their food organisms which kingfishers consume on most natural waters can easily be considered as a small tax, gladly given, for the esthetic virtues of this bird.

That there are possible benefits as well as undesirable effects of predation has often been stated (*e.g.*, Lagler, 1944). A detailed discussion of this matter does not appear to be desirable here.

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FISHERY CONSERVATION THROUGH EDUCATION

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Abstract

The Fish and Wildlife Service has formed an organization to engage in commercial fishery education. This section will prepare and collect instructional motion-picture films, film strips, manuals, leaflets, displays, and other visual material; arrange demonstrations; offer consulting services; sponsor training courses in colleges; and arrange cooperative training programs with fishery organizations. Training will include tested and approved methods for fishing, handling of products, distribution, fish cookery, and sanitation.

If conservation means wise use of a natural resource, then the attainment of conservation can be facilitated by educational facilities to transmit knowledge of the best practices to those who are using the resource. When resources are abundant there is a tendency to overlook the need for careful planning in conservation, and it usually is not until signs of depletion become evident that steps are taken to correct inefficient and careless methods of exploitation. So it is in the commercial fisheries. Although the supplies of fish in the waters of the United States still are reasonably plentiful, some fisheries for individual species have declined seriously, with the result that farsighted and progressive leaders in industry and in government are looking to educational means for promoting better utilization of the marine products harvested. Sound exploitation means more than merely regulating the size and composition of the catch as the fish are taken from the water; it means that proper methods of utilization must be applied on shore as well. Educational work is necessary in teaching methods of preparing top-quality fishery products, in showing the value of elimination of wastage in preparation, and in demonstrating to the ultimate consumer the proper ways of handling and cooking the products that come from the fishery resource at sea.

On some occasions the fishing industry, recognizing the importance of this type of instruction, has undertaken educational campaigns, but these programs generally have been sectional activities and therefore limited in scope. In order to reach all of those concerned in the industry as well as those who are consumers of fishery commodities, it has become a function of the Federal Government to sponsor a fishery-educational program. Although the establishment of an educational section in the Fish and Wildlife Service is not a new idea, this objective was not realized until funds were made available in 1946 for the purpose. This organization has developed an extensive program designed to meet immediately the most urgent problems capable of solution by educational means. Long-range and more comprehensive projects will be undertaken to the extent that facilities permit.

One of the primary steps in the program has been the development of additional fishery-education material. Many of the basic data necessary are already available in scientific and technical reports but not in a form for ready use in the general education field. To present this information to those who will make most use of it, the Educational Section is preparing manuals, fishery-educational leaflets, and other textual material. Several educational motion pictures have been produced and other training films and film strips to teach fishing methods, handling, processing, distribution, fish cookery, and sanitation are in the process of production. Visual instruction of this type is particularly valuable in vocational training courses, as well as for rapid instruction of persons who do not have an extensive academic background. Fishery displays also have been prepared. Posters and other graphic material will be drawn up for distribution.

In bringing information to the industry on improved techniques and more efficient methods of operation as currently developed in the Fish and Wildlife research laboratories, the Educational Section is working closely with fishery operators, fishermen, fishermen's unions, and other interested groups. Demonstrations and lectures on approved methods for the catching, dressing, icing, processing, and transporting of fishery products are given by competent technologists of the Educational Section's staff, or by specialists in the trade who sometimes cooperate in the program. These activities will help to make directly available in a practical form the findings of the Service's research staffs. This information under the present circumstances frequently remains little used by other than researchers because of the purely scientific terminology in which it is written.

At some important fishing ports, trained specialists are on hand to offer personal consulting services to fishermen, shippers, and processors in solving technical problems.

The home-economics unit within this section demonstrates proper fish-cookery methods to consumer groups. Elimination of wastage caused by poor preparation is stressed at these meetings and more frequent use of presently little used species of fish and new fishery products is emphasized.

One of the most important phases of the educational work to be undertaken as the program develops further will be the sponsoring of commercial-fishery courses at colleges and other educational institutions. Because of the very limited number of courses now offered throughout the United States, there is little or no opportunity for students to secure fishery education other than that pertaining purely to biological aspects. The lack of educational facilities has been one of the greatest handicaps to the technical advancement of the fisheries, since trained graduates have not been available for the many important positions in industry, in Government, and in schools and colleges as instructors. The contrast between the lack of college-trained fishery experts and the wealth of trained agricultural experts is striking. It might also be pointed out that many foreign countries are far ahead of the United States in maintaining commercial-fishery schools and experimental fishing vessels that turn out considerable numbers of skilled fishery technicians each year. For these reasons, there is a paramount need for this Government to sponsor fishery courses in vocational schools, maritime academies, colleges, universities, and other institutions that may have the facilities for arranging this type of instruction. Preliminary investigations have shown that many schools would welcome the opportunity to add commercial-fishery courses to their curricula, but the lack of instructors and text-book material required in teaching has long been a handicap difficult to overcome. It is desirable to develop at least a few schools of fisheries where students can major in commercial-fishery work for a bachelor's degree. The sponsoring of fishery courses must be given early attention; and when complete surveys can be made to determine the extent of the present facilities that might be adapted to this work, this part of the program will be expanded as rapidly as circumstances permit.

The work of the Educational Section is a forward step in the right direction, but accomplishment of all objectives in this field will require many years of coordinated effort. It is certain, however, that the value of a sound educational program cannot be overestimated as a factor in maintaining the fisheries and the fishing industry in a healthy condition.

TRENDS IN THE LAKE TROUT FISHERY OF LAKE HURON THROUGH 1946

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CONTENTS

Page
Abstract ... 121
Introduction ... 122
Materials and methods ... 123
Trends of production of lake trout in the major regions of Lake Huron, 1879-1946 ... 125
  United States ... 125
  Canada, Lake Huron proper ... 125
  Canada, Georgian Bay ... 127
  Canada, all Lake Huron waters ... 128
  All waters of Lake Huron ... 129
Production of lake trout in the districts of the United States waters of Lake Huron, 1891-1908 and 1929-1946 ... 129
Abundance of lake trout in the districts of the United States waters of Lake Huron, 1929-1946 ... 135
Intensity of the fishery for lake trout in the districts of the United States waters of Lake Huron, 1929-1946 ... 139
Relationships among production, abundance, and fishing intensity, especially during the recent decline ... 143
Literature cited ... 146

ABSTRACT

The production of lake trout, *Cristivomer namaycush* (Walbaum), in the United States waters of Lake Huron was highest in the earliest years for which there are statistical records, averaging 2,362,000 pounds in 1879–1894. The general level of yield was much lower but relatively stable in 1895–1939, during which period the catch averaged 1,685,000 pounds. The most recent years have seen a rapid and calamitous decline in the output; setting a new record low each year, the take decreased from 940,000 pounds in 1940 to only 38,000 pounds in 1946.

The production of lake trout in the Canadian waters of Lake Huron was generally low from 1867 up to about 1883, apparently because the fishery was then in the process of development. After 1882 the yield was relatively high for 26 years and then fell away progressively as the following averages of production in pounds for different periods show: (1883–1908) Huron proper—1,749,000, Georgian Bay (including the North Channel)—2,475,000, Canadian total—4,224,000; (1909–1922) Canadian total (no data for regions within the lake)—3,753,000; (1923–1939) Huron proper—1,600,000, Georgian Bay—1,996,000, Canadian total—3,596,000. During more recent years the catch fell from 1,038,000 pounds in 1940 to 29,000 pounds in 1946 in Huron proper, from 1,688,000 to 702,000 pounds in Georgian Bay, and from 2,726,000 to 731,000 pounds in all Canadian waters.

The tremendous decreases in production that have occurred in all parts of Lake Huron in recent years are generally believed to have been caused by a reduction in the abundance of lake trout resulting from attacks by the sea lamprey, which has become established and has multiplied rapidly in the upper Great Lakes.

Data are available on the production of lake trout in six local regions or statistical districts of the United States waters of Lake Huron (boundaries shown in Fig. 1) in 1891–1908 and on production, fishing intensity, and the abundance of fish on the grounds in 1929–1946. The order of the districts with respect to their percentage contribution to the average annual production was the same in 1891–1908 and 1929–1943. Certain changes occurred, nevertheless, in all percentages. The northern districts (H-1, H-2) which contributed 70.3 percent of the take in 1891–1908 accounted for only 56.2 percent in 1929–1943 whereas the central (H-3, H-4) and southern (H-5, H-6) districts which yielded 18.7 and 11.0 percent, respectively, in the former period contributed 25.5 and 18.3 percent in the latter.

The six districts were similar in 1929–1946 in that in all of them (1) most of the years of highest output and of most intensive fishing occurred in the early to middle 1930's and (2) the earlier high levels were followed by declines that ultimately reduced production and fishing intensity to insignificance. The same (earlier high values followed by a decline) held for the abundance of lake trout in the northerly five districts, but the trends of fluctuation in the abundance in H-6 were opposite those in other areas.

On the whole, the abundance of lake trout appeared to have little effect on fishing intensity for the species. Only in H-1 did the two exhibit significant positive correlation whereas in H-6 they showed highly significant negative correlation. Most of the factors that may counteract the expected influence of abundance on fishing intensity (economic conditions, weather, . . .) cannot be evaluated accurately. It was determined, however, that the collapse of the whitefish fishery in the middle and late 1930's most probably exerted a significant depressing effect on the intensity of the gill-net fishery for lake trout in those districts (H-1, H-4, H-6) in which the two species are ordinarily captured together.

The estimated abundance of lake trout in the United States waters of Lake Huron (all districts combined) had reached an extremely low level in 1946 (24 percent of the 1929–1943 average), and the complete collapse of the fishery in late years is a matter of record. The rate of decline in abundance, however, was much less rapid than the spectacular decreases in production might suggest. Although each year beginning with 1940 saw a new record low yield, the abundance was still 87 percent of average in 1942 and did not drop below 70 percent until 1944. This seeming paradox is explained by the fact that relative to average conditions, fishing intensity in 1941–1946 was lower and was decreasing much more rapidly than was abundance.

INTRODUCTION

The recent collapse of the lake trout fishery of Lake Huron represents the fourth major catastrophe to overtake a Great Lakes fishery within 25 years. The first was the disappearance of the cisco (*Leucichthys artedi*) in Lake Erie in the years following 1924; the second, the failure of the whitefish (*Coregonus clupeaformis*) fishery in Lake Huron in the middle and late 1930's; the third, the 1942–1943 mortality of smelt (*Osmerus mordax*) which all but exterminated that species in Lakes Michigan and Huron.

The known or suspected causes of these calamities have varied widely. According to Van Oosten (1930) the disappearance of the Lake Erie cisco can be explained best as the result of excessively heavy fishing in 1923 and 1924 at a time when abnormal weather conditions caused the ciscoes to be concentrated in the "deep hole" in the eastern end of the lake. The collapse of the Lake Huron whitefish fishery was proven incontrovertibly by Van Oosten, Hile, and Jobes (1946) to have been caused by overfishing with the deep trap net, a phenomenally destructive gear. The mortality of the smelt, on the other hand, was not man's doing; here a communicable disease, bacterial or virus, provides the only explanation consistent with all of the circumstances of the epidemic (Van Oosten, 1947). It appears likely that the decline of the lake trout in Lake Huron also can be termed an act of God, for the rapid disappearance of that fish has been associated with the spread and increase in the abundance of the parasitic sea lamprey (*Petromyzon marinus*). Here, man has contributed only indirectly to the debacle through his construction of the Welland Canal by way of which the lamprey is believed to have reached the upper Great Lakes.

It is not the purpose of this paper to discuss the problem of the sea lamprey in the Great Lakes or even to weigh the evidence that this parasite has been a major factor in the decrease of lake trout in Lake Huron.[1] Rather, it is intended here to give a statistical account of the changes that have taken place in the lake trout fishery—to follow the general trends of production in the major areas of the lake since the early days of the fishery, to trace the annual fluctuations in the yield in United States waters within limited areas (statistical districts) over the 18-year period, 1929–1946, and to analyze these local fluctuations in relation to the accompanying changes in fishing intensity and in the estimated abundance of lake trout.

Dr. John Van Oosten, Chief, Great Lakes Investigations, was helpful in criticising the original manuscript of this report. The figures were prepared by Mr. Howard J. Buettner.

MATERIALS AND METHODS

The records of production as given in Table I for the United States (State of Michigan) waters of Lake Huron through 1940 were taken from Gallagher and Van Oosten (1943) and were from the sources listed in that publication; the statistics for later years were tabulated in the Great Lakes laboratory of the Fish and Wildlife Service as were also the records of take in local areas of United States waters in 1891–1908 (Table 3). The figures on the Canadian (Province of Ontario) catch through 1939

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[1] See Applegate (1947), Schneberger (1947), MacKay and MacGillivray (1949), and Shetter (1949) for reviews of the sea lamprey problem, for brief statements of the program of the Great Lakes Sea Lamprey Committee set up by the Great Lakes States, the Province of Ontario, and the Fish and Wildlife Service, and for certain data obtained in recent investigations of the sea lamprey.

TABLE 1.—*Production (thousands of pounds) of lake trout in Lake Huron, 1879–1946*

Year	United States (Mchigan)	Canada (Ontario)			Grand total
		Huron proper	Georgian Bay[1]	Total	
1879	2,084	410	183	593	2,677
1880	....	1,046	425	1,471	....
1881	....	831	382	1,213	....
1882	....	1,369	613	1,982	....
1883	....	1,511	1,870	3,381	....
1884	....	1,894	2,187	4,081	....
1885	2,540	1,498	2,476	3,974	6,514
1886	....	1,101	2,217	3,318	....
1887	....	1,139	2,092	3,231	....
1888	....	1,302	2,305	3,607	....
1889	2,181	1,029	2,780	3,809	5,990
1890	1,750	1,657	3,250	4,907	6,657
1891	2,816	1,219	3,418	4,637	7,453
1892	2,382	2,626	2,467	5,093	7,475
1893	3,106	2,464	1,914	4,378	7,484
1894	2,039	2,523	2,644	5,167	7,206
1895	1,875	2,156	2,357	4,513	6,388
1896	1,527	1,741	2,727	4,468	5,995
1897	1,292	1,058	1,736	2,794	4,086
1898	1,299	2,001	2,146	4,147	5,446
1899	1,460	2,535	2,689	5,224	6,684
1900	1,732	1,559	2,276	3,835	5,567
1901	1,608	1,769	2,253	4,022	5,630
1902	1,739	1,808	1,994	3,802	5,541
1903	1,724	1,993	2,568	4,561	6,285
1904	2,016	1,471	3,168	4,639	6,655
1905	1,987	1,697	3,496	5,193	7,180
1906	1,966	1,901	2,849	4,750	6,716
1907	1,831	1,998	2,255	4,253	6,084
1908	1,382	1,819	2,229	4,048	5,430
1909	....	....	....	3,330	....
1910	....	....	....	3,690	....
1911	....	....	....	4,174	....
1912	1,050	....	....	3,860	4,910
1913	2,163	....	....	3,689	5,852
1914	1,366	....	....	3,198	4,564
1915	1,774	....	....	4,867	6,641
1916	1,798	....	....	4,931	6,729
1917	2,111	....	....	3,695	5,806
1918	2,614	....	....	3,738	6,352
1919	2,322	....	....	3,407	5,729
1920	1,220	....	....	2,946	4,166
1921	1,358	....	....	3,212	4,570
1922	1,828	....	....	3,804	5,632
1923	1,827	1,705	1,714	3,419	5,246
1924	1,394	1,872	1,918	3,790	5,184
1925	1,615	1,740	2,058	3,798	5,413
1926	1,685	1,441	2,226	3,667	5,352
1927	1,692	1,670	2,482	4,152	5,844
1928	1,598	1,460	2,221	3,681	5,279
1929	1,283	1,680	2,035	3,715	4,998
1930	1,729	1,266	1,669	2,935	4,664
1931	2,049	1,215	1,633	2,848	4,897
1932	2,165	1,292	1,676	2,968	5,133
1933	1,970	1,343	1,816	3,159	5,129
1934	1,576	1,562	1,958	3,520	5,096
1935	1,743	2,069	2,186	4,255	5,998
1936	1,400	2,138	2,177	4,315	5,715
1937	1,340	1,754	2,148	3,902	5,242
1938	1,270	1,747	2,053	3,800	5,070
1939	1,372	1,250	1,953	3,203	4,575
1940	940	1,038	1,688	2,726	3,666
1941	892	1,110	1,713	2,823	3,715
1942	728	800	1,398	2,198	2,926
1943	459	517	1,092	1,609	2,068
1944	363	316	824	1,140	1,503
1945	173	117	745	862	1,035
1946	38	29	702	731	769

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[1] Includes the North Channel

were obtained from Ford (1943); those for 1940 and later years were taken from the Reports of the Ontario Department of Game and Fisheries (now the Department of Lands and Forests) or obtained by correspondence with officials of that organization.

The compilations of catch statistics and the estimates of the annual fluctuations in the abundance of lake trout and in the intensity of the fishery for that species in the several statistical districts of the United States water of Lake Huron (see Fig. 1 for the boundaries of the six districts) were made in the Great Lakes laboratory from commercial fishing reports supplied through the cooperation of the Michigan Department of Conservation. The methods of analysis have been described in sufficient detail in earlier publications (Hile, 1937; Hile and Jobes, 1941; Van Oosten, Hile, and Jobes, 1946), so that the discussion of them here would be superfluous. Suffice it to state that the estimates of abundance were derived from actual records of the catch per unit of effort of the principal gears producing lake trout in the various districts and that the estimates of fishing intensity were based on the amount of gear (linear feet of gill nets; number of hooks; number of pound nets) lifted that actually took lake trout.

TRENDS OF PRODUCTION OF LAKE TROUT IN THE MAJOR REGIONS OF LAKE HURON, 1879–1946

United States.—The catch of lake trout in the United States waters stood at a relatively high level in the earlier years (Table 1). In 7 of the 8 years of the period 1879–1894 for which there are statistics (no records are available for years before 1879) the take exceeded 2 mllion pounds, and in one year (1893) it was above 3 million pounds. The average annual production for the period was 2,362,000 pounds (Table 2).

In the years 1895–1939 the general level of the output did not change. Considerable fluctuations did occur, to be sure, but such trends as can be detected must be described as short-term. In 21 or half of the 42 years of the period for which there are records the take was between 1½ and 2 million pounds. Fourteen years had production of less than 1½ million pounds (lowest catch, 1,050,000 pounds in 1912), and 7 had yields above 2 million pounds (greatest catch, 2,614,000 pounds in 1918). The mean output for 1895–1939 was 1,685,000 pounds.

The value of the mean for the 7 years 1940–1946 (513,000 pounds) was less than a third of that for 1895–1939. Far more significant, however, than this small average is the rate at which the catch declined, setting a new record low each year, from 940,000 pounds in 1940 to only 38,000 pounds in 1946.[2]

For practical purposes the lake trout fishery in the State of Michigan waters of Lake Huron had disappeared in the latter year.

Canada, Lake Huron Proper.—The take of lake trout was relatively low

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[2] The downward trend that culminated in the low yield of 1946 actually started in 1936.

TABLE 2.—*Production (thousands of pounds) of lake trout in Lake Huron over certain periods of years*

United States (Michigan)		Canada (Ontario)						Entire Lake	
		Huron proper		Georgian Bay[1]		Total			
Period of years	Average production	Period of years	Average production	Period of years	Average production	Period of years	Average production	Period of years	Average production
1879–1894	2,362	1879–1882	914	1879–1882	401	1879–1882	1,315	1879	2,677
1895–1939	1,685	1883–1908	1,749	1883–1908	2,475	1883–1908	4,224	1885–1894	6,968
1940–1946	513	1923–1939	1,600	1923–1939	1,996	1909–1922	3,753	1895–1908	5,978
. . .	. . .	1940–1946	561	1940–1946	1,166	1923–1939	3,596	1912–1922	5,541
. . .	. . .	. . .	. . .	. . .	. . .	1940–1946	1,727	1923–1939	5,226
. . .	. . .	. . .	. . .		. . .	. . .	. . .	1940–1946	2.240

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[1] Includes the North Channel

during the first 3 or 4 years for which data are given in Table 1[3] (mean of 914,000 pounds for 1879–1882). In 1883 and 1884, however, the catch had reached approximately the level that characterized the period 1883–1908. The average for the 26 years was 1,749,000 pounds. In 6 of these years production was greater than 2 million pounds (maximum of 2,626,000 pounds in 1892), and in 8 it was less than 1½ million pounds (minimum of 1,029,000 pounds in 1889).

Statistics are lacking for 1909–1922.[4] The general level of production probably declined slightly during this period, however, as the catches for 1923–1939 fluctuated about a mean of 1,600,000 pounds—149,000 pounds less than the average for 1883–1908. The output exceeded 2 million pounds in 2 of the 17 years of the 1923–1939 period (maximum of 2,138,000 pounds in 1936) and was below 1½ million pounds in 7 years (minimum of 1,215,000 pounds in 1931).

In the Ontario as in the United States waters of Lake Huron proper, production declined rapidly in recent years (the downward trend became distinct in 1940). Excepting only 1889 and certain years prior to 1882 when the fishery was just undergoing development, it can be said that the 1940 catch of 1,038,000 pounds set a record low. A slight increase to 1,110,000 pounds in 1941 was followed by a rapid drop to only 29,000 pounds in 1946. The 1940–1946 mean of 561,000 pounds was only 35.1 percent of the average for 1923–1939 and 32.1 percent of that for 1883–1908.

Canada, Georgian Bay.—In Georgian Bay (including the North Channel) as in the Canadian waters of Lake Huron proper, production was low in the earlier years (mean of 401,000 pounds in 1879–1882—see also Footnote 3). Beginning in 1883, however, the catch was much higher. For the years 1883–1908, the average output was 2,475,000 pounds. The take exceeded 3 million pounds in 4 of the 26 years (maximum of 3,496,000 pounds in 1905) and was less than 2 million pounds in 4 years (minimum of 1,736,000 pounds in 1897).

Again, as in Lake Huron proper, statistics are lacking for 1908–1922 (see Footnote 4) and again the level of production in 1923–1939 (mean of 1,996,000 pounds) was lower (by 479,000 pounds) than that of the earlier years, 1883–1908. In 1923–1939 the yield did not reach 2½ million pounds in any one of the 17 years (maximum of 2,482,000 pounds in 1927) and dropped below 2 million pounds in 8 years (minimum of 1,669,000 pounds in 1930).

The recent decline in the output of lake trout in Georgian Bay and the North Channel proceeded less rapidly than in other major areas. Indeed, the establishment of periods comparable with those for other waters constitutes the only reason for the selection of 1940 as the first year in the most recent period. It was not until 1942 that the catch (1,398,000 pounds) was lower than that recorded in any earlier year since 1882. The average for 1940–1946 (1,166,000 pounds) was 58.4 percent of that for 1923–1939 but only 47.1 percent of the 1882–1908 mean.

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[3] The catch was low also in 1867-1878 in Huron proper and in other Canadian waters of the lake as well—statistics not published here since records are lacking for United States waters before 1879. See Ford (1943) for Canadian statistics for the earlier years.

[4] Van Oosten, Hile, and Jobes (1946) published statistics on the take of whitefish in these years, but did so only because of evidence that the data on that species were not impaired seriously by changes in the official definition of the different regions within Canadian waters. With lake trout, on the contrary, these changes were highly damaging to the statistics; hence the data for 1909-1922 must be omitted.

Canada, All Lake Huron Waters.—The trend of the total production of lake trout in Canadian waters was much the same as that in Lake Huron proper and Georgian Bay individually. The low annual yield of earlier years (mean of 1,315,000 pounds for 1879–1882—see also Footnote 3) was followed by 26 years of relatively high production. In 1883–1908 the take averaged 4,224,000 pounds (range from 2,794,000 pounds in 1897 to 5,224,000 pounds in 1899). The average output in 1909–1922, the period for which there are no statistics for the individual areas within Canadian waters, was 3,753,000 pounds or 471,000 pounds below the mean for 1883–1908. The range in this period was from 2,946,000 pounds in 1920 to 4,931,000 pounds in 1916. The average annual catch dropped further to 3,596,000 pounds in 1923–1939 (range, 2,848,000 pounds in 1931 to 4,315,000 pounds in 1936). During the most recent period (1940–1946) the yield in every year but 1941 was less than that in any previous year since 1882. The decline was continuous and rapid from 2,823,000 pounds in 1941 to only 731,000 pounds in 1946. The 1940–1946 average of 1,727,000 pounds was only 40.9 percent., and the 1946 catch was but 17.3 percent of the earlier, 1883–1908 mean.

TABLE 3.—*Production (thousands of pounds) of lake trout in the State of Michigan waters of Lake Huron, 1891–1908*

Year	Production in district						Total
	H-1	H-2	H-3	H-4	H-5	H-6	
1891	1,528	877	222	159	13	18	2,816
1892	569	1,122	89	167	359	75	2,382
1893	667	1,245	370	186	535	103	3,106
1894	576	700	284	88	309	82	2,039
1895	640	499	359	73	125	179	1,875
1896	515	420	301	94	115	81	1,527
1897	468	549	142	87	4	42	1,292
1898	299	648	116	97	97	42	1,299
1899	325	720	201	54	129	31	1,460
1900	477	804	283	43	107	18	1,732
1901	553	635	247	31	101	41	1,608
1902	469	582	389	60	210	29	1,739
1903	579	486	399	59	164	37	1,724
1904	726	709	344	47	157	33	2,016
1905	602	727	364	59	195	40	1,987
1906	841	717	250	63	57	38	1,966
1907	856	547	253	84	54	38	1,831
1908	766	302	170	55	66	23	1,382
Average	636	683	266	84	155	53	1,877
Percentage	33.9	36.4	14.2	4.5	8.2	2.8	....

All Waters of Lake Huron.—Because of certain differences in the trends of production of lake trout in United States and Canadian waters, the nature of which may be seen from the preceding discussion and the examination of the data of Tables 1 and 2, six periods are desirable in describing the course of the fishery in Lake Huron as a whole. The year 1879 (production, 2,677,000 pounds) has been set out alone, since at that time the catch was relatively high in the United States but low in Canada. In 1885–1894 the take was high in both countries. The yield for the entire lake exceeded 7 million pounds in 4 of the 7 years for which there are data and averaged 6,968,000 pounds. The catch of 7,484,000 pounds in 1893 is the largest for which we have a record. Later declines (first principally in the United States and then largely in Canada) led to successive decreases in the average annual output to 5,978,000 pounds in 1894–1908, 5,541,000 pounds in 1912–1922, and 5,226,000 pounds in 1923–1939. The most recent period (1940–1946), except for a small recovery in 1941, was one of rapid decline. The average of 2,240,000 pounds was only 32.1 percent, and the 1946 take of 769,000 pounds only 11.0 percent of the mean for the earlier period, 1885–1894. In fact, the take in every one of the four years, 1943–1946, was less than that of any earlier year, not even excluding 1879 when Canadian production was extremely low.

PRODUCTION OF LAKE TROUT IN THE DISTRICTS OF THE UNITED STATES WATERS OF LAKE HURON, 1891–1908 AND 1929–1946

As a preliminary to the description of the more recent changes of production, it appears desirable to present the available data on the catch of lake trout in the various local regions of the United States waters of Lake Huron (see Fig. 1 for boundaries of the statistical districts) in the earlier years of the fishery (Table 3).[5] These statistics for 1891–1908 probably supply a better idea of the relative natural productive capacities of the different areas than is to be had from the recent figures (particularly from the data for the years of rapidly declining output).

During the 18 years, 1891–1908, the production of lake trout was centered in the more northerly districts, H-1 and H-2, which produced on the average 33.9 and 36.4 percent, respectively, of the total for the lake.[6] In the remaining four districts the percentages[7] ranged from 2.8 percent in

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[5] The statistics for 1891-1908 were compiled in the Great Lakes laboratory from original records supplied by the Michigan Department of Conservation. We are indebted to the W.P.A. for assistance in that project.

[6] In this and following sections "the lake" or "Lake Huron" refers to the United States waters only.

[7] In all probability the percentage and average for H-3 are too high and those for H-4 correspondingly too low. The original records on which Table 3 is based gave the annual production by ports without reference to the grounds actually fished. A considerable part of the gill-net operations of fishermen from Oscoda (Au Sable), the leading port of district H-3, are conducted, however, on the "Middle Grounds" in H-4 off the mouth of Saginaw Bay. Any catches made in those H-4 waters by Oscoda fishermen in 1891-1908 were credited to H-3. It is not believed that the 1891-1908 data for any other districts were distorted to an important extent by compilation of catch statistics by port. The 1929-1946 data were unaffected by this type of error, since in those years each day's catch of each fisherman was assigned to the district in which the fish actually were taken.

H-6 to 14.2 percent in H-3. The extent to which production was concentrated in the more northerly part of the lake is brought out by the following percentages for the northern, central, and southern regions: northern (H-1, H-2), 70.3 percent; central (H-3, H-4), 18.7 percent; southern (H-5, H-6), 11.0 percent.

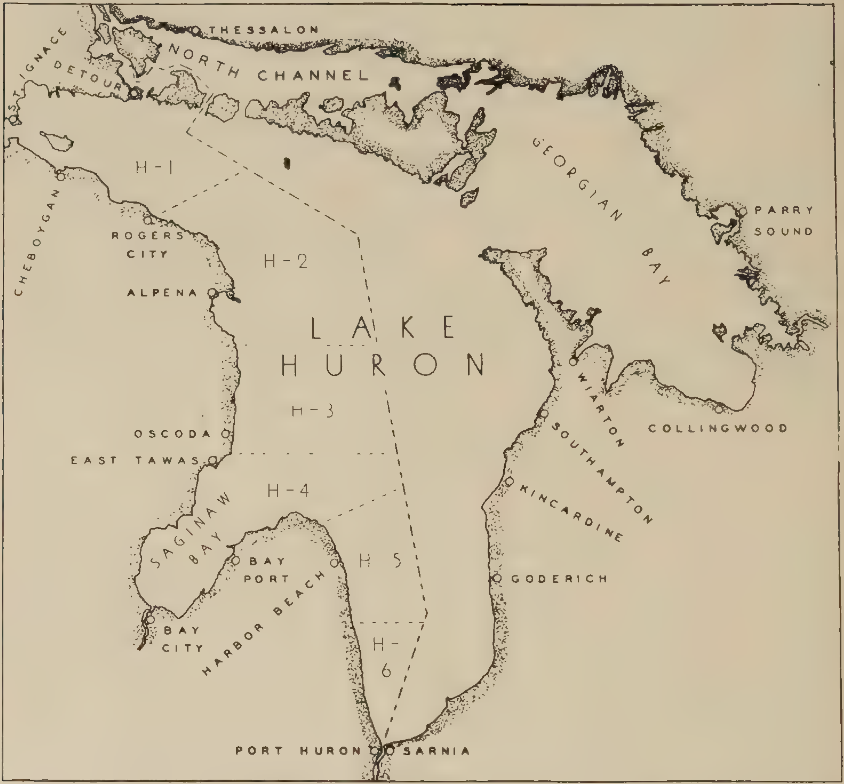
THESSALON
NORTH CHANNEL
ST. IGNACE
DETOUR
CHEBOYGAN
H-1
ROGERS CITY
ALPENA
H-2
GEORGIAN BAY
PARRY SOUND
LAKE HURON
WIARTON
COLLINGWOOD
SOUTHAMPTON
KINCARDINE
H-3
OSCODA
EAST TAWAS
H-4
SAGINAW BAY
BAY PORT
HARBOR BEACH
H 5
GODERICH
BAY CITY
H-6
PORT HURON
SARNIA

FIGURE 1.—Chart of Lake Huron showing the boundaries of the statistical districts, H-1 to H-6, in United States waters.

A description of the annual fluctuations of yield in the individual districts in 1891–1908 does not seem to be desirable here. It may be mentioned, however, that in each district the range of fluctuation was large but that despite this variability the several districts maintained their relative positions with respect to the percentage contribution to the total for the lake with a good degree of consistency. First and second positions in production were held by districts H-1 and H-2 in every year (H-2 first 10 times and H-1 first 8 times). Similarly, H-3 was third in production in

15 of the 18 years, H-5 fourth in 9 years, H-4 fifth in 10 years, and H-6 sixth in 14 years.

The order of the districts with respect to the percentage contribution to the average annual total for the lake was the same in 1929–1943 (Table 4)[8] as in 1891–1908; that is, the arrangement from highest to lowest average catch in each period was: H-2, H-1, H-3, H-5, H-4, and H-6. Some relatively large changes should be noted, however, in the percentages, which were lower in 1929–1943 than in 1891–1908 in districts H-1 and H-2 but higher in the four remaining districts. The degree to which production had shifted toward the south is illustrated by the following comparison:

TABLE 4.—*Production (thousands of pounds) of lake trout in the State of Michigan waters of Lake Huron, 1929–1946*

Year	Production in district						Total
	H-1	H-2	H-3	H-4	H-5	H-6	
1929	394	331	168	200	135	54	1,283
1930	500	511	199	264	194	62	1,729
1931	569	590	225	325	249	91	2,049
1932	550	684	180	304	367	79	2,165
1933	446	608	215	246	355	100	1,970
1934	292	564	227	162	265	65	1,576
1935	342	724	309	60	248	62	1,743
1936	362	572	200	38	181	46	1,400
1937	312	411	206	96	277	39	1,340
1938	286	366	215	90	286	26	1,270
1939	261	431	305	89	271	14	1,372
1940	194	327	176	77	158	8	940
1941	133	390	174	91	86	18	892
1942	93	319	210	60	28	18	728
1943	60	130	153	70	23	24	459
1944	28	87	125	74	27	23	363
1945	12	49	72	14	11	15	173
1946	2	7	25	2	[1]...	2	38
Average[2]	320	464	211	145	208	47	1,394
Percentage[2]	22.9	33.3	15.1	10.4	14.9	3.4	....

[1] Less than 500 pounds
[2] For 1929–1943

Region of lake	*Percentage of total production*		*Ratio of percentages*
	1891–1908	1929–1943	
Northern (H-1, H-2)	70.3	56.2	0.80
Central (H-3, H-4)	18.7	25.5	1.36
Southern (H-5, H-6)	11.0	18.3	1.66

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[8] The 15 years, 1929-1943, have been taken as a "normal period" or "period of reference" for statistical analyses of the commercial fisheries of the State of Michigan waters of the Great Lakes. Since fluctuations are to be described largely in relation to mean conditions during that period, the averages in the tables in this paper that deal with the 1929-1946 fishery are for the 1929-1943 period rather than for the full 18 years. In Table 4 the inclusion of data for 1944-1946 would have affected the percentages slightly but would not have changed the ranking of the districts.

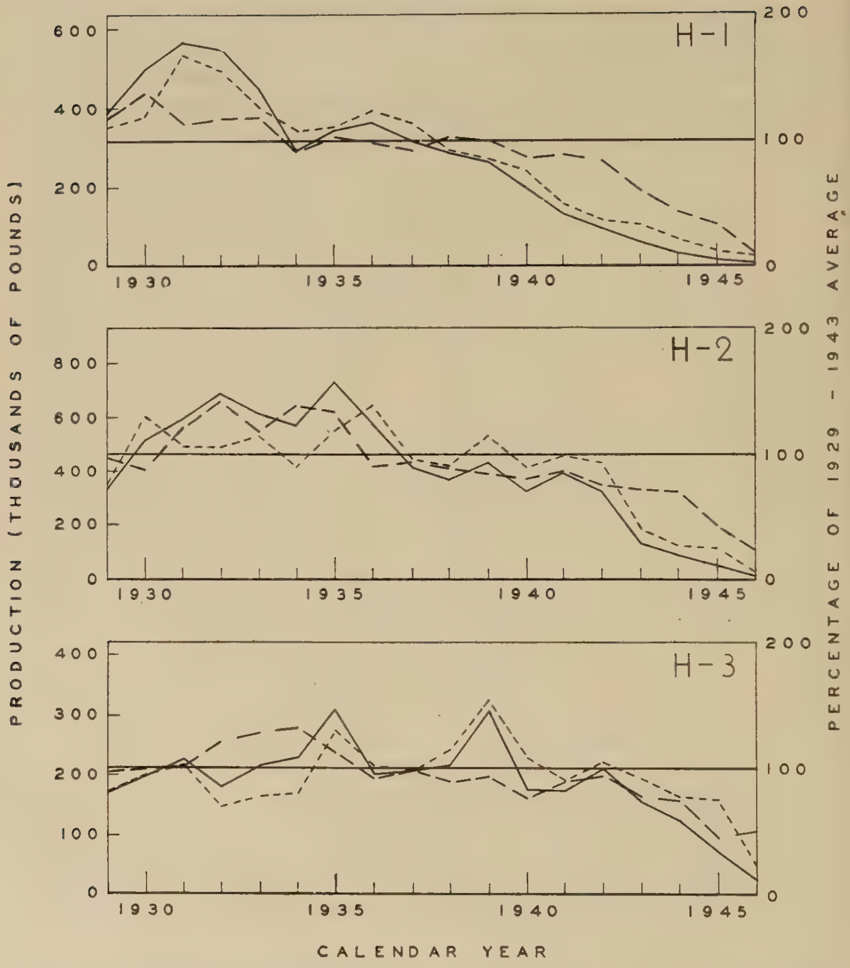

FIGURE 2.—Production (solid line) and index of abundance (long dashes) of lake trout and fishing intensity for the species (short dashes) in districts H-1, H-2, and H-3, 1929-1946, expressed as percentages (scale at right) of the 1929-1943 mean. Production given also in pounds (scale at left).

From the above it is seen that relatively the northern region was only 0.80 as productive in the more recent as in the earlier period, whereas the central and southern regions were more productive (ratios of 1.36 and 1.66, respectively).

Despite certain important differences of detail, the trends of production of lake trout in the statistical districts of Lake Huron in 1929–1946

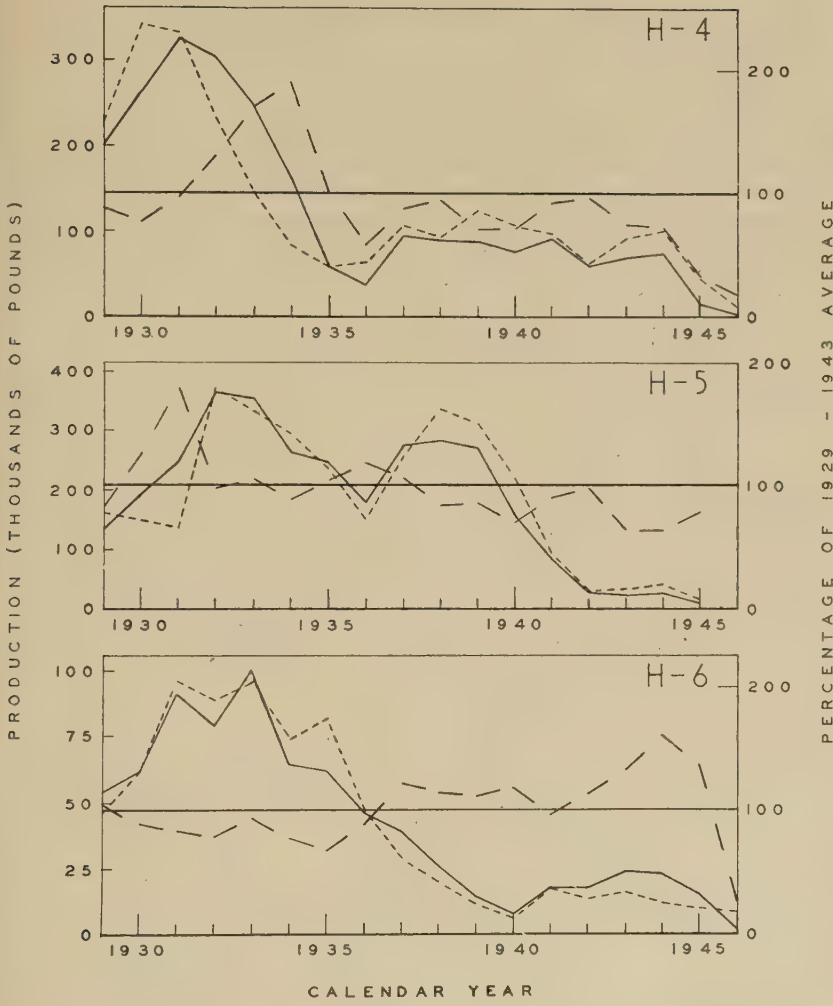

FIGURE 3.—Production (solid line) and index of abundance (long dashes) of lake trout and fishing intensity for the species (short dashes) in districts H-4, H-5, and H-6., 1929–1946, expressed as percentages (scale at right) of the 1929–1943 mean. Production given also in pounds (scale at left).

exhibited numerous similarities (Table 4 and Figs. 2 and 3). In all of them the output tended to be heaviest in the early 1930's. This fact is well demonstrated by the listing of the three years of highest production in each district (upper part of Table 5). Here only 2 of 18 entries were outside the 6-year range, 1930–1935, and 13 were within the 4-year range,

TABLE 5.—*Summary of certain of the data of Tables 4, 6, and 11 on the annual fluctuations of production, abundance, and fishing intensity in the lake trout fishery of the United States waters of Lake Huron, 1929–1946*

Item	District						Entire lake
	H-1	H-2	H-3	H-4	H-5	H-6	
Three years, greatest production	1931 1932 1930	1935 1932 1933	1935 1939 1934	1931 1932 1930	1932 1933 1938	1933 1931 1932	1932 1931 1933
Last year, production average or greater	1936	1936	[1]1942	1934	1939	[2]1936	1936
First year, recent progressive decline...	1937	1942	1943	1945	[3]1945	1944	1940
First year, production less than half average	1941	1943	1945	[4]1945	1941	[4]1944	1943
Three years, greatest abundance	1930 1929 1933	1932 1934 1935	1934 1933 1932	1934 1933 1932	1931 1930 1936	1944 1945 1943	1932 1934 1933
Last year, abundance average or greater	1939	1935	1935	1935	1937	1945	1935
First year, recent progressive decline....	1942	1942	[5]1943	1943	[6]1943	1945	1942
First year, abundance below 70 percent..	1943	1945	1945	[7]1945	1943	[7]1946	1944
Three years, greatest intensity	1931 1932 1933	1936 1930 1935	1939 1935 1938	1930 1931 1932	1932 1938 1933	1931 1933 1932	1932 1931 1930
Last year, intensity average or greater.	1937	1939	1942	1933	1940	1936	1939
First year, recent progressive decline...	1937	1942	1943	1945	[8]1945	1944	1940
First year, intensity less than half average	1941	1943	1946	[9]1945	1941	1938	1943

[1] Production slightly (less than 0.5 percent) below average

[2] Production slightly (less than 1.5 percent) below average

[3] 1939 if exception in 1944 is ignored. See Table 4

[4] First recent year; catch was below 50 percent in some years preceding the last one above 50 percent. See Table 4

[5] Figure for 1946 showing increase (see Table 6) based on limited data

[6] "Progressive" decline lacking; drop to lower level in 1943. See Table 6

[7] First recent year; abundance below 70 percent in H-4 in 1936 and in H-6 in 1935. See Table 6

[8] 1939 if exceptions in 1943 and 1944 are ignored. See Table 11

[9] First recent year; intensity was below 50 percent in some years preceding the last one above 50 percent. See Table 11

1930–1933 (H-3 was the only district with but one of its three high-production years within the latter period). The districts resembled each other again in that the decline from the high yields tended to be irregular in each of them and in that each ultimately entered on a progressive decline that was to carry production to new all-time lows—indeed, to the point of insignificance. The timing of these changes, however, varied from district to district. For example, the last year with approximately average production or better was as early as 1934 (H-4) and as recent as 1942 (H-3). Similarly, the recent progressive decline got under way as early as 1937 (H-1) and as late as 1945 (H-4, H-5). Again, the first recent year with an output less than half the 1929–1943 mean ranged from 1941 (H-1, H-5) to 1945 (H-3, H-4).

Regardless of differences of timing, however, the end result was the same in all districts—a decline of the yield amounting practically to the disappearance of the fishery.

Production in the entire lake (as was to be expected) followed a similar course. The highest yields took place in 1931 to 1933, the last year of above-average production was 1936, the recent decline started in 1940, the first year with a catch less than half of average was 1943, and the take in 1946 was insignificantly small (38,000 pounds or less than 3 percent of the 1929–1943 mean). As was mentioned in the preceding section, every year beginning with 1940 set a new record low.

ABUNDANCE OF LAKE TROUT IN THE DISTRICTS OF THE UNITED STATES WATERS OF LAKE HURON, 1929–1946

The information on the phenomenal decline in the yield of lake trout in Lake Huron constitutes prima-facie evidence that disaster has overtaken the population. Certainly the production of a species so high-priced and in such great market demand would not dwindle away unless the stock no longer could be exploited profitably. On the other hand, the known decreases in the output cannot be taken as measures of the decline in the availability of fish. A proper understanding of the changes that have occurred requires the examination of the production statistics in relation to the annual fluctuations in the estimated abundance of marketable lake trout on the grounds and in the intensity of the fishery for that species.

As was explained earlier (p. 125) the abundance percentages (Table 6) are based on actual records of the success of fishing and have been computed by methods described in detail in earlier publications. It may be added here, however, that in the lake trout fishery of Lake Huron the catch per unit of effort of large-mesh gill nets (Table 7) exerts the greatest influence on the value of the percentage. Large-mesh gill nets took 55.3 percent of the total Lake Huron production of lake trout in 1929–1940 and 89.5 percent in 1941–1946. Of lesser significance but nevertheless important were set hooks (Table 8) which accounted for 31.6 percent of the 1929–1940 take and for 6.8 percent of the 1941–1946 catch. The

TABLE 6.—*Abundance of lake trout, 1929–1946, in the State of Michigan waters of Lake Huron according to statistical district and for the districts combined*

[Expressed as percentages of the 1929–1943 mean]

Year	Abundance percentage in district						Average[1]
	H-1	H-2	H-3	H-4	H-5	H-6	
1929	118	96	97	88	82	106	99
1930	138	87	99	77	127	90	105
1931	112	121	102	97	179	84	121
1932	117	142	121	130	98	79	123
1933	118	117	129	170	105	94	122
1934	90	138	132	190	89	78	122
1935	102	133	112	101	104	68	113
1936	97	90	92	59	118	89	93
1937	91	93	98	88	106	122	96
1938	102	88	89	95	84	115	92
1939	100	83	93	71	86	112	89
1940	85	80	76	71	70	119	79
1941	88	86	89	92	90	97	88
1942	83	75	94	96	98	114	87
1943	59	71	77	75	64	133	71
1944	43	70	75	72	64	161	67
1945	33	43	45	32	78	137	48
1946	9	23	51	18	[2]...	23	24

[1] In the computation of the average the abundance percentage of each district was weighted by the percentage of the total 1929-1943 production contributed by that district

[2] Production insignificant; no estimate of abundance possible

TABLE 7.—*Catch (pounds of lake trout per lift of 10,000 linear feet of large-mesh gill nets (4½ inches and greater, extension measure) in the several districts of the State of Michigan waters of Lake Huron, 1929–1946*

Year	Catch per lift of 10,000 feet of large-mesh gill nets					
	H-1	H-2	H-3	H-4	H-5	H-6
1929	114	183	150	122	156	81
1930	149	167	142	112	157	67
1931	111	264	157	147	118	62
1932	124	270	176	202	127	57
1933	138	228	202	277	120	69
1934	88	252	219	310	138	58
1935	112	239	175	214	162	51
1936	107	216	142	[1]832	174	69
1937	124	159	151	140	232	91
1938	136	153	138	157	171	86
1939	128	189	134	114	209	85
1940	102	162	126	115	141	88
1941	108	172	134	144	119	73
1942	96	144	145	152	118	85
1943	62	141	118	119	78	99
1944	46	141	115	114	84	120
1945	36	84	69	50	94	104
1946	9	45	78	28	[2]..	17
Average[3]	113	196	154	161	148	75

[1] Based exclusively on the catch of nets set on reef in November; not included in computation of average. The average was estimated on the assumption that had a usable figure been available for 1936, that figure would have given the same estimate of abundance as the one actually obtained from data for other gear (set hooks) for the same year

[2] No production by gill nets

[3] For 1929–1943

only other gear that produced sufficient lake trout to be employed in the estimation of abundance was the pound net in district H-1 (Table 9). In the earlier years, 1929–1934, pound nets yielded an average of more than 62,000 pounds per year or between 13 and 14 percent of the total for the district. Subsequently the take of lake trout by pound nets in H-1 declined rapidly and has not been above 7,000 pounds since 1938.

TABLE 8.—*Catch (pounds) of lake trout per lift of 1,000 set hooks in the several districts of the State of Michigan waters of Lake Huron, 1929–1946*

[When figures are not given, few or no lake trout were taken with this gear]

Year	Catch per lift of 1,000 set hooks					
	H-1	H-2	H-3	H-4	H-5	H-6
1929	323	216	153	185	97	123
1930	256	194	224	169	244	. . .
1931	291	238	188	148	432	237
1932	249	313	450	231	192	200
1933	229	252	108	69	208	203
1934	279	320	154	91	165	110
1935	269	319	165	88	191	133
1936	215	164	164	71	209	135
1937	156	256	168	89	183	. . .
1938	201	222	135	70	147	. . .
1939	160	156	197	69	137	. . .
1940	113	161	101	37	103	. . .
1941	136	153	227	160	152	. . .
1942	85	172	172	. . .	. . .	. . .
1943	146	96	223	59	. . .	. . .
1944	. . .	87	185	. . .	76	. . .
1945	. . .	. . .	. . .	. . .	. . .	. . .
1946	. . .	. . .	. . .	. . .	. . .	. . .
Average[1]	207	215	189	109	184	191

[1] For 1929–1943. See Footnote 1 to Table 7 for comment on estimation of 15-year average when data are lacking for some years of the period

In the five northerly districts (H-1 to H-5) the greatest abundance as well as the greatest production occurred in the early 1930's (Table 6 and middle section of Table 5). In the listing of the three years of greatest abundance for these districts, 12 of the 15 entries were within the 5-year period, 1931–1935. Further points of resemblance between the annual

TABLE 9.—*Catch (pounds) of lake trout per lift of one pound in district H-1 of the State of Michigan waters of Lake Huron*

Year	Catch per lift of one pound net	Year	Catch per lift of one pound net	Year	Catch per lift of one pound net
1929	31	1935	12	1941	6
1930	32	1936	15	1942	5
1931	23	1937	18	1943	5
1932	25	1938	14	1944	5
1933	21	1939	10	1945	2
1934	19	1940	13	1946	3
Average for 1929–1943					17

fluctuations of production and abundance in these five districts were: the declines from the early high levels were irregular; a downward trend led ultimately to extremely low levels; the timing of the changes varied from district to district.

To illustrate the last of the points just listed, the most recent year with abundance at the 1929–1943 average (100) or above ranged from 1935 to 1939. The onset of the recent progressive decline (1942 in two districts and 1943 in three—see Footnotes 5 and 6 to Table 5) and the first recent year (see Footnote 7 to Table 5) with abundance below 70 percent[9] (1943 in two districts and 1945 in three) did not, however, vary widely.

TABLE 10.—*Coefficients of correlation* (r) *between annual fluctuations in the abundance percentages of lake trout in the statistical districts of the State of Michigan waters of Lake Huron, 1929–1945*

[Absolute values of *r* corresponding to probabilities *(p)* of 0.05 and 0.01 are 0.482 and 0.606 respectively]

District	District					
	H-1	H-2	H-3	H-4	H-5	H-6
H-1	...	0.634	0.711	0.420	0.571	−0.750
H-2	0.634	...	0.910	0.784	0.437	−0.821
H-3	0.711	0.910	...	0.885	0.385	−0.760
H-4	0.420	0.784	0.885	...	0.140	−0.544
H-5	0.571	0.437	0.385	0.140	...	−0.597
H-6	−0.750	−0.821	−0.760	−0.544	−0.597	...

Whereas the trends of annual fluctuations in abundance were similar to each other in the first five districts, they tended to be opposite the trend in H-6. In that district abundance was relatively low in the early and middle 1930's, and the years of highest abundance were 1944, 1945, and 1943. In 1946 the estimated abundance was extremely low in H-6 as well as in districts H-1 to H-5, but as explained previously the yield was so small in that year in all areas (2,000 pounds or less in four of them and only 25,000 pounds in the most productive one—H-3) that the percentages cannot be considered very reliable.

Some quantitative measure of the extent of the agreements and disagreements just noted is provided by the data of Table 10 in which are recorded the coefficients of correlation (*r*) between the abundance percentages of the districts over the 17 years, 1929–1945 (percentages for 1946 were excluded as too unreliable). Of the 10 coefficients that could be computed among the five more northerly districts all were positive, 1 was "significant" ($0.05 > p > 0.01$) and 5 were "highly significant" ($p < 0.01$). All correlations between the abundance percentages for H-6 and the more northerly districts were negative; 2 of the 5 were significant, and 3 were highly significant. Thus we have strong evidence that the changes in the availability of lake trout to commercial fishermen followed the same general trend in the first five districts and that the trend in H-6 was the reverse of that in more northerly waters. Speculation as to the explanation for these similarities and dissimilarities would be to no point in view of our present lack of information on the factors that control the abundance of the lake trout.

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[9] The use of the 50-percent level as was done with the analagous item in the data for production (and fishing intensity—see later) was not practical since the fishery had all but disappeared by the time that level of abundance was reached (it was not reached in H-5 before the yield dropped to less than 500 pounds in 1946). It must be recognized that the reliability of the abundance percentages declined rapidly as production decreased in recent years; those for 1946 in particular are based on such limited data as to be of limited significance other than to demonstrate an extremely low level. Inexact as the estimates of abundance may have become in the more recent years as quantitative measures of the availability of lake trout, they serve nevertheless to prove that the actual returns per unit of fishing effort were dropping off rapidly as the fishery was disappearing.

The estimates of the annual fluctuations in abundance in the six districts combined (right of Table 6) followed the trend that characterized districts H-1 to H-5. (The conflicting trend of H-6 had little effect on these estimates, since that district yielded only 3.4 percent of the 1929–1943 output and hence received a small weight in the computation of the weighted means—see Footnote 1 to Table 6.) The highest abundance occurred in 1932, 1934, and 1933; the last year with abundance above the 1929–1943 average was 1935; the recent decline started in 1942; and in 1944 the abundance had dropped below 70 percent.

INTENSITY OF THE FISHERY FOR LAKE TROUT IN THE DISTRICTS OF THE UNITED STATES WATERS OF LAKE HURON, 1929–1946

In the data on the annual fluctuations in fishing intensity (Table 11 and bottom section of Table 5) may be found once more a general pattern similar to that which held for fluctuations in production (and in abundance in the first five districts). Fourteen of the 18 entries in the record of the years of greatest fishing intensity in the individual districts fell within the period, 1930–1935 (compared with 16 of 18 entries within the same period in the corresponding record for production and 12 of the 15 entries for the districts H-1 to H-5 within the period 1931–1935 in the data on abundance). Again, too, the timing of the declines from the earlier high values varied considerably: the last year with fishing intensity at average or above was as early as 1933 and as late as 1942; the recent progressive decline (see Footnote 8 to Table 5) started from 1937 to 1945; and the first recent year (see Footnote 9 to Table 5) with fishing intensity below 50 percent of average ranged from 1938 to 1946.

For the combined districts fishing intensity rose continuously from 1929 to a maximum of 131 percent of the 1929–1943 mean in 1932, varied irregularly at a somewhat lower level in 1933–1939, and started in 1940 on a progressively downward trend that led to a value of only 9 percent in 1946.

Among the factors that might be expected to influence the annual fluctuations in fishing intensity, the abundance of the lake trout itself is among the more obvious since a plentitude of fish should stimulate operations and a scarcity depress them. Yet a comparison of the data of Tables 6 and 11

TABLE 11.—*Intensity of the fishery for lake trout in the State of Michigan waters of Lake Huron, 1929–1946*

[The unit corresponds to 1/1,500 of the total expected catch for all districts over the 15-year period, 1929–1943]

Year	Units of fishing intensity in district						Total
	H-1	H-2	H-3	H-4	H-5	H-6	
1929	24.1	25.0	12.5	16.4	11.9	3.7	93.6
1930	26.1	42.6	14.5	24.8	11.0	5.0	124.0
1931	36.9	35.1	15.9	24.1	10.0	7.8	129.8
1932	34.1	34.9	10.8	16.9	27.0	7.2	130.9
1933	27.4	37.6	12.1	10.5	24.5	7.7	119.8
1934	23.5	29.5	12.4	6.2	21.6	6.0	99.2
1935	24.2	39.2	20.0	4.3	17.3	6.6	111.6
1936	27.0	45.8	15.7	4.7	11.1	3.8	108.1
1937	24.9	31.9	15.2	7.8	18.8	2.3	100.9
1938	20.2	30.1	17.5	6.9	24.6	1.6	100.9
1939	18.8	37.7	23.7	9.1	22.8	0.9	113.0
1940	16.5	29.3	16.7	7.8	16.2	0.5	87.0
1941	10.9	32.8	14.1	7.1	6.9	1.4	73.2
1942	8.0	30.9	16.1	4.5	2.1	1.1	62.7
1943	7.3	13.2	14.2	6.8	2.5	1.3	45.3
1944	4.7	8.9	12.0	7.4	3.0	1.0	37.0
1945	2.6	8.2	11.6	3.3	1.0	0.8	27.5
1946	1.7	2.1	3.6	0.8	[1]...	0.7	8.9
Average[2]	22.0	33.1	15.4	10.5	15.2	3.8	100.0

[1] Less than 0.05

[2] For 1929–1943

for the individual districts (see also Figs. 2 and 3) offers little support to the view that the abundance of lake trout was an important factor in determining the intensity of fishing for that species in any but the more recent years when abundance had fallen to an extremely low level. It is true that in H-1 fishing intensity and the abundance of lake trout seem to have followed similar courses. In H-2 to H-5, however, despite the above-mentioned similarity as to the general period of years in which the highest values of abundance and intensity occurred, the agreement as to detail is so poor that the two appear to fluctuate independently or even to follow opposite trends. In H-6 the tendency for fishing intensity to be high when the abundance was low is clearly noticeable.

The general observations just made are supported by the coefficients of correlation between the annual percentage fluctuations in fishing intensity and the abundance of lake trout in the individual districts. For the purpose of computing these coefficients, data for years later than 1941 were excluded, since it was feared that the disruptive effects of war-time scarcities of gear, equipment, and experienced fishermen would obscure relationships that normally might exist. The coefficients (r) between abundance and fishing intensity for 1929–1941 were as follows:

District	r	*District*	r
H-1	0.561	H-4	−0.068
H-2	−0.005	H-5	−0.375
H-3	−0.459	H-6	−0.800

Of the above the positive coefficient for H-1 is significant, and the negative one for H-6 is highly significant.[10] Whereas, in the absence of evidence to the contrary, the coefficient for H-1 might be taken to indicate that a high abundance of lake trout stimulates and a low abundance depresses fishing operations for the species, it would hardly be concluded that the converse relationship holds in H-6 and possibly tends to be present in H-3 and H-5. The most acceptable interpretation holds that, indispensable as the lake trout may be to the conduct of a lake trout fishery, the abundance of that species is only one of the factors, and in some situations a subordinate factor, in the determination of fishing intensity.

Among the more important of the factors other than the abundance of lake trout that probably affected fishing intensity in 1929–1941 may be mentioned economic conditions (market demand and price, operational costs, . . .), weather, and the abundance of other species of fish. The status of our knowledge does not permit a discussion of the first two of these factors. There is good evidence, however, that in some districts the extent of fishing for lake trout with large-mesh gill nets was affected profoundly by fluctuations in the abundance of whitefish. On *a priori* grounds one would expect this effect to be greatest in districts H-1, H-4, and H-6 in which operations with large-mesh gill nets are conducted largely on relatively shallow grounds where both lake trout and whitefish are captured and deep-water grounds on which the nets can be fished for lake trout only are limited or absent. The fishing with large-mesh gill nets in these districts is essentially a two-species operation [11] dependent for its success on the capture of both lake trout and whitefish. A sharp increase or decline in the availability of one species accordingly may be expected to stimulate or depress fishing intensity even though the fluctuations in the abundance of the other species are small. In the remaining three districts (H-2, H-3, and H-5), on the other hand, the bulk of the gill-net fishing for lake trout is carried on in deep water on grounds on which few whitefish occur. Here during periods of high abundance of whitefish a "two-species" fishery may be operated in the shallower water, but if whitefish become scarce the gill nets can be shifted to deeper water where they take lake trout alone.

That the facts conform well with the expectations just set forth is indicated by the data of Table 12 where it may be seen that the fluctuations in the abundance of whitefish and in the intensity of the gill-net fishery for lake trout in 1929–1941 (see p. 140 concerning cause for exclusion of data for years later than 1941) were closely similar. How close the agreement was is demonstrated by the coefficients of correlation between the two variables in the three districts: H-1, 0.752; H-4, 0.804; H-6, 0.916. All three values were far above the level considered highly significant (Foot-

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[10] With 11 degrees of freedom the absolute values of r corresponding to the 5- and 1-percent levels of probability are, respectively, 0.553 and 0.684.

[11] Catches of such species as suckers (*Catostomus* spp.), burbat (*Lota lota*), and yellow pikeperch (*Stizostedion vitreum vitreum*) constitute an unimportant part of the total catch (especially as regards value) on the whitefish-lake trout grounds.

TABLE 12.—*Comparison of annual fluctuations in the abundance of whitefish (AW) and in the intensity of the gill-net fishery for lake trout (IT) in Lake Huron*

[Expressed as percentages of the 1929–1939 mean in H-3 and as percentages of the 1929–1941 mean in the remaining districts. Data on abundance of whitefish adapted from Van Oosten, Hile, and Jobes (1946)]

Year	District											
	H-1		H-2		H-3		H-4		H-5		H-6	
	AW	IT	AW	IT	AW	IT	AW	IT	AW	IT	AW	IT
1929	139	144	150	91	301	89	175	158	188	141	150	103
1930	195	118	204	161	183	105	242	260	265	158	200	145
1931	152	164	199	73	261	101	259	227	267	90	191	221
1932	116	142	87	72	115	69	217	117	169	62	223	194
1933	92	103	99	87	67	81	101	80	122	77	149	174
1934	101	113	118	79	55	74	56	58	112	95	131	133
1935	86	101	101	110	25	135	67	6	54	81	70	130
1936	100	100	79	95	22	103	53	3	28	87	68	68
1937	84	55	50	111	26	100	62	72	26	69	45	53
1938	62	47	72	91	26	122	20	57	22	96	27	37
1939	57	76	65	82	19	121	11	91	9	101	15	15
1940	56	82	36	103	..[1]	97	20	84	14	129	16	9
1941	60	55	40	145	..[1]	102	17	87	24	114	15	18

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[1] Inadequate data

note 10). In the remaining districts (H-2, H-3, and H-5) the annual fluctuations in the abundance of whitefish and in the intensity of the gill-net fishery for lake trout in 1929–1941 (1929–1939 in H-3) were to all appearances independent. True, there is some indication of a negative correlation in H-3, but the value of the coefficient ($r = -0.304$) was far too small to be significant.[12]

The extent to which the abundance of whitefish affected fishing intensity for lake trout after 1941 is problematical. Of possibly greater importance were the war-time shortages of equipment and skilled labor and in the most recent years the great scarcity of the lake trout itself (abundance high in H-6, however, as late as 1945).

RELATIONSHIPS AMONG PRODUCTION, ABUNDANCE, AND FISHING INTENSITY, ESPECIALLY DURING THE RECENT DECLINE

On the basis of extensive statistical data on the commercial fisheries of the Great Lakes it was stated in an earlier paper (Van Oosten, Hile, and Jobes, 1946) that, ". . . there is good reason to believe that under normal conditions (without disruption in the methods or regulations of the fishery), over limited areas, and for short periods of years, large increases or decreases of production may serve as reliable indicators of increases or decreases in the abundance of fish on the grounds. The changes in annual yields do not measure the changes in abundance, but merely indicate their occurrence." As may be seen from a comparison of the data of Tables 4 and 6—see also Figures 2 and 3—this relationship held reasonably well for the lake trout in the majority of the statistical districts of Lake Huron and failed entirely only in the most southerly district, H-6, where the trends of production and abundance tended to be opposite.

The patterns of fluctuation in production and in abundance resembled each other most closely in districts H-1 and H-2. In these districts the coefficients of correlation (r) between the deviations of production and abundance from the 1929–1945 mean (1946 data held inadequate—see p. 138) were, respectively, 0.889 and 0.880. Both values were far above the level customarily termed highly significant ($r = \pm 0.606$ at $p = 0.01$ when $df = 15$). The correlation was not as strong in H-3 ($r = 0.621$) as in the northerly districts but was still highly significant. The value of r was still lower in H-4 (0.512) and H-5 (0.412) but was "significant" in the former ($r = \pm 0.482$ at $p = 0.05$) and at the 10-percent level in the latter ($r = \pm 0.412$ at $p = 0.10$).

These positive and mostly significant correlations, it should be emphasized, provide evidence only of greater or lesser similarity in the trends of fluctuation of production and abundance. They offer no justification at all for any attempt to measure changes in abundance from changes in production. Only a glance at Figures 2 and 3 is required to see how misleading it would be to estimate abundance, even in H-1 and H-2, from the much more variable production.

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[12] With 9 degrees of freedom the absolute value of r corresponding to the 5-percent level of probability is 0.602.

The highly significant negative correlation between production and abundance in H-6 ($r = -0.688$) has its principal explanation, of course, in the depressing effect of the collapse of the whitefish fishery on the intensity of operations with large-mesh gill nets (p. 141). It seems likely also that the correlation between the abundance and production of lake trout might have been higher in districts H-1 and H-4 but for the similar depressing effect of the drop in the abundance of whitefish on gill-net fishing in those areas. The effect was doubtless small, however, in H-1 where the abundance of lake trout and whitefish followed closely similar trends (compare data of Tables 6 and 12). Thus the scarcity of whitefish tended to depress fishing intensity in H-1 when lake trout were scarce and to stimulate it when lake trout were relatively plentiful. This situation doubtless contributed to the significant correlation between fishing intensity and the abundance of lake trout in the district (p. 140). In the remaining three districts the lack of correlation between fishing intensity and the abundance of lake trout (H-2) or a tendency toward a negative correlation (H-3 and H-5) prevented closer correspondence between production and abundance, but in those regions, as was explained in the previous section, we have no good information on the factors controlling fishing intensity.

For the six districts combined (Table 13 and Fig. 4) production seems to have served reasonably well as an indicator of the occurrence of increases and decreases of abundance. Although each increase or decrease of yield was not invariably accompanied by a change of abundance in the same direction, it is to be noted that every year with production above the 1929–1943 average also had better than average abundance. Conversely, the take was below the average in every year but 1936 (when it was exactly at the mean) in which the abundance percentage was less than 100. How closely the fluctuations in abundance and production were correlated is demonstrated by the value of the coefficient ($r = 0.948$) for the period 1929–1945.

TABLE 13.—*Fluctuations in the production and abundance of lake trout and in the intensity of the lake trout fishery in the United States waters of Lake Huron, 1929–1946*

[Expressed as percentages of the 1929–1943 average]

Year	Production	Abundance	Intensity	Year	Production	Abundance	Intensity
1929	92	99	[1]93	1938	91	92	101
1930	124	105	124	1939	99	89	113
1931	147	121	130	1940	67	79	87
1932	155	123	131	1941	64	88	73
1933	142	122	120	1942	52	87	63
1934	113	122	99	1943	33	71	45
1935	125	113	112	1944	26	67	37
1936	100	93	108	1945	12	48	28
1937	96	96	101	1946	3	24	9

[1] Actual value, 93.6; rounded to 93 to give a 1929–1943 total of 1,500

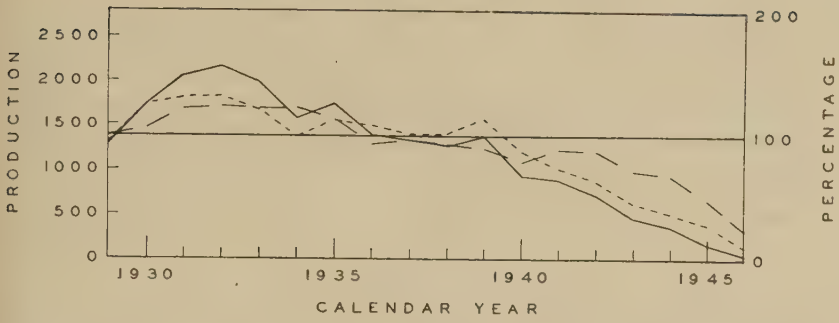

FIGURE 4.—Production (solid line) and index of abundance (long dashes) of lake trout and fishing intensity for the species (short dashes) in the combined districts of Lake Huron, 1929-1946.

In spite of the close agreement between production and abundance with respect to the direction of departure from the 1929–1943 mean, for the whole lake as well as for the individual districts, conclusions based on production as to the rate and extent of the changes in abundance could have been most misleading. The point is of special interest as it applies to the recent decline of the fishery. As was stated earlier (p. 125); see also Table 1), each year subsequent to 1939 set a new record low for the production of lake trout in the United States waters of Lake Huron. It was this spectacular decline that occasioned deep and widespread alarm concerning the imminent destruction of the stocks. The actual abundance of lake trout, however, decreased much less rapidly than did production. An increase occurred as recently as 1941, and in both 1941 and 1942 the level of abundance was only a little below that of such earlier years as 1936, 1938, and 1939. Furthermore, abundance was still above the 70-percent level in 1943 when the catch had fallen to a third of the 1929–1943 average and was only slightly below 70 percent in 1944 when the yield was but a quarter of the mean. It was not until 1945 and 1946 that truly low levels of abundance (48 and 24 percent, respectively) were reached.

The data on fishing intensity explain the enormous drop in yield during years when the abundance of lake trout still was not excessively low. In only the first (1940) of the record-low years did the intensity percentage exceed the abundance percentage. During all later years fishing intensity was relatively lower than the abundance. In 1942, for example, fishing intensity had dropped to less than two-thirds (63 percent) of average, whereas abundance was 87 percent. Again, in 1943 and 1944 when the abundance percentages were 71 and 67, the intensity values were only 45 and 37. Even in 1945 and 1946 when abundance was extremely low (48 and 24) fishing intensity was lower yet (28 and 9). It may be concluded, then, that decreasing fishing intensity contributed much more than did declining abundance to the recent drop in the output of lake trout in the United States waters of Lake Huron.

There is small comfort in the knowledge that the abundance of lake trout in Lake Huron did not decline as rapidly as the figures on production might suggest, for certainly the abundance in 1946 had dropped to a level that justified the gloomiest forebodings of those who were alarmed by the decreasing yields of preceding years. The lake trout had become so scarce in 1946 that it could not support any substantial amount of fishing. At the time of preparation of this report (in early 1948) final statistics for 1947 are not available, but preliminary tabulations indicate a yield of approximately 15,000 pounds. Staff members of this Service who visited Lake Huron ports from August 18 to August 31, 1947, for the primary purpose of collecting information on lake trout with special reference to the effects of sea lampreys actually were able to examine a total of only 11 specimens.

It is without doubt fortunate that the rapidly declining fishing intensity caused the catch to fall as rapidly as it did, for the tremendous decline focused public attention on the menace of the sea lamprey, and most probably led to earlier support of research projects designed to determine whether, and if so, by what means, that parasite may be controlled.

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RECENT INVESTIGATIONS ON THE SEA LAMPREY, *PETROMYZON MARINUS,* IN ONTARIO

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Abstract

Little Thessalon River is an important spawning ground for the sea lamprey, as compared with Desbarats, MacBess, Livingstone, and Lauzon Creeks. More research is necessary to determine the reasons for this difference.

The selection of areas by the sea lamprey for spawning confirms the observation of Coventry (1922). Furthermore, the sea lampreys entered the weirs at night, the majority 1 or 2 hours past midnight. Sea lampreys were taken during the earlier period of the sucker run. The majority of the sea lampreys averaged 24 inches in total length. Seventy-five percent of the suckers were scarred, presumably by lampreys. As the numbers of sea lampreys increased the numbers of suckers decreased.

Hoop nets are not effective for trapping sea lampreys. Metal weirs are essential, and the wings should be 5 feet deep, measured vertically from the bed of the stream, in order to avoid an overflow during periods of heavy rainfall. To avoid the escape of lampreys the floor of the trap must be screened, and the lead should have a skirt of screening buried in the bed of the stream to a depth of approximately 5 inches. For successful operation the entrance to the trap should be flush with the bottom of the stream.

Doubts as to the mortality of sea lampreys after spawning appear untenable, in view of the observation by Gage (1928).

Introduction

The sea lamprey, *Petromyzon marinus,* the silver lamprey, *Ichthyomyzon unicuspis,* the Michigan brook lamprey, *Ichthyomyzon fossor,* and the American brook lamprey, *Entosphenus lamottenii,* occur in Ontario. The sea lamprey and the silver lamprey are parasitic; the Michigan brook lamprey and the American brook lamprey are non-parasitic.

The sea lamprey has two distinct dorsal fins and the buccal funnel has a series of teeth radiating in all directions from the mouth. Hubbs and Lagler (1941) described the distribution of this species as follows: "North Atlantic Ocean from Iceland and northern Europe to northwestern Africa, and from the Grand Banks and the Gulf of St. Lawrence (and perhaps from Labrador) to Florida. Landlocked in Lake Champlain and Lake Ontario (and tributary lakes) from which it has recently spread through canals to become well established in lakes Erie, Huron and Michigan." On the other hand, the silver lamprey has unicuspid, circumoral teeth and the dorsal fin is continuous. Hubbs and Lagler (1941) have described its distribution as follows: "Interior regions from the Ohio River to the western tributaries of Hudson Bay; basins of Lakes Superior (near west end only), Michigan (chiefly in the main lake and bays), Huron, Erie, and Ontario (rare and local in Lake Ontario); the St. Lawrence River drainage (below eastern end of Lake Ontario) and Lake Champlain. Generally in larger lakes and rivers."

Radforth (1944) cited only one record of the occurrence of the Michigan brook lamprey in Ontario, namely, a specimen taken from a small tributary of the Thames River, near Harrington. In Ontario the American brook lamprey was recorded by Radforth only from streams flowing into the western end of Lake Ontario. Like the sea lamprey this species has two distinct dorsal fins but unlike the former it has weak teeth.

The earlier descriptions of the life history of the sea lamprey are those of Jordan and Fordice (1885) and the comprehensive study by Gage (1893) of the variety occurring in Cayuga, Seneca, and similar lakes of northern New York. Bensley (1915) included *Petromyzon marinus* provisionally in his list of fishes of Georgian Bay on the reports of fishermen that lampreys 15 inches long were sometimes taken on whitefish and lake trout from deep water. Accessible records of the lampreys of eastern Canada were compiled by Huntsman (1917). Coventry (1922) described the breeding habits of the landlocked sea lamprey in the Humber River, just west of Toronto. The same year Dymond (1922) recorded a specimen 21 inches long taken November 8, 1921, in Lake Erie at Merlin by Mr. A. E. Crewe. Gage (1928) gave an inclusive and valuable account of the lampreys of New York State, their life history and economics. Dymond, Hart, and Pritchard (1929) have given an account of the damage reported to lake trout, pike, and whitefish, by the sea (lake) lamprey in Lake Ontario, and of the size frequency of the latter.

Radforth (1944) presented interesting facts and possibilities with a view to explaining the migration and establishment of the sea lamprey in the upper Great Lakes. The construction of the Welland and Trent Canals gave access to the Great Lakes beyond Lake Ontario, and the evidence available apears to favor the former route. The following reference on the Welland Canal is taken from the Encyclopaedia Americana, Volume 51:

> The first canal was opened November 27, 1829, and extended from Port Dalhousie on Lake Ontario to the Welland River which was utilized as far as its outlet to the Niagara River. Vessels then ascended the Niagara to Lake Erie. In 1833 a diversion was made by extending the canal to Port Colborne on Lake Erie. In 1842 improvements and enlargements were made and in 1875 a new cutting was begun from Allanburg to Port Dalhousie. In 1912 further enlargements were undertaken at an estimated cost of $50,000,000. The old channel is used from Port Colborne to Thorold and from there a new cutting was made to Lake Ontario, entering the lake about three miles east of Port Dalhousie.

During recent years the sea lamprey has been reported to be increasing rapidly in Lake Huron, Georgian Bay, and North Channel, to

TABLE 1.—*Production (pounds) of lake trout in the different regions of the Province of Ontario waters of Lake Huron, 1923–1945*

[The statistics of catch of lake trout for Lake Superior for the same period have been omitted since they have been more or less stable]

Year	Lake Huron proper	Georgian Bay	North Channel	Total
1925	1,739,468	1,588,982	469,525	3,797,975.00
1926	1,441,194	1,482,257	743,909	3,667,360.00
1927	1,669,572	1,726,272	756,225	4,152,069.00
1928	1,460,179	1,583,168	637,380	3,680,727.00
1929	1,680,338	1,622,443	412,447	3,715,228.00
1930	1,266,306	1,317,134	351,323	2,934,763.00
1931	1,214,487	1,289,258	344,022	2,847,767.00
1932	1,292,462	1,313,210	362,652	2,968,324.00
1933	1,343,366	1,344,425	471,194	3,158,985.00
1934	1,562,275	1,330,895	626,720	3,519,890.00
1935	2,069,223	1,475,312	710,907	4,255,442.00
1936	2,137,519	1,472,586	704,657	4,314,762.00
1937	1,753,699	1,504,194	694,025	3,951,918.00
1938	1,747,281	1,426,874	626,072	3,800,227.00
1939	1,250,115	1,448,917	504,365	3,203,397.00
1940	1,038,776	1,334,033	354,058	2,726,867.00
1941	1,109,786	1,501,631	211,597	2,823,014.00
1942	800,095	1,274,333	123,414	2,197,842.00
1943	517,399	1,066,463	25,508	1,609,370.00
1944	315,828	815,153	9,177	1,140,158.00
1945	117,410	737,591	7,165	862,166.00

TABLE 2.—*Production (pounds) of whitefish in the different regions of the Province of Ontario waters of Lake Huron, 1923–1945*

Year	Lake Huron proper	Georgian Bay	North Channel	Total
1925	121,524	1,255,408	240,473	1,617,405.00
1926	155,351	1,126,787	238,268	1,520,406.00
1927	191,494	1,559,583	214,400	1,965,477.00
1928	224,262	1,357,736	210,531	1,792,529.00
1929	204,761	1,089,975	295,341	1,590,077.00
1930	246,551	993,873	192,446	1,432,870.00
1931	245,157	980,944	233,974	1,460,075.00
1932	219,227	1,194,810	167,999	1,582,036.00
1933	309,519	1,475,359	257,697	2,042,575.00
1934	308,939	1,382,929	252,903	1,944,771.00
1935	340,327	1,292,228	304,084	1,936,639.00
1936	235,304	983,783	260,247	1,479,334.00
1937	286,981	1,122,895	254,235	1,664,111.00
1938	205,230	1,196,159	185,682	1,587,071.00
1939	115,061	1,118,017	157,238	1,390,316.00
1940	92,403	887,235	118,847	1,098,485.00
1941	93,058	747,983	85,128	926,169.00
1942	113,865	583,922	84,945	782,732.00
1943	113,259	441,501	49,087	603,847.00
1944	142,455	364.368	30,788	537,611.00
1945	66,139	279.285	21.791	367.215.00

be doing inestimable damage to fish in these waters, and to be responsible for depleted catches of the more important varieties, namely, lake trout and whitefish, particularly the former.

The statistics of catch of lake trout (*Cristivomer namaycush*) and whitefish (*Coregonus clupeaformis*) for these waters from 1925 to 1945, are contained in Tables 1 and 2. The records of these tables bring out clearly the present sharp downward trend of production that is causing such grave concern to the industry and fishery administrators.

Information from Questionnaires on the Sea Lamprey

In an attempt to secure information on the distribution and abundance of sea lampreys and on the frequency of their attacks on lake trout, whitefish, and other species, 424 mimeographed copies of the following questionnaire were distributed to commercial fishermen of Lake Huron and eastern Lake Superior:

To:
Licensed Commercial Fishermen
Lake Huron, Georgian Bay, North Channel and Lake Superior.
Dear Sir: RE: LAMPREY.

During the past year the Department has received reports of parasitism of lake trout by the sea lamprey, a species which has become established in the Upper Great Lakes and particularly in Lake Huron and it adjacent areas, Georgian Bay and North Channel. This particular lamprey is considered dangerously parasitic. Please answer the following questions, sign and return to the Department of Game and Fisheries, Fish Culture Branch, Room 1520, East Block, Parliament Buildings, Toronto 2, when you are returning your answers to the questionnaire re. closed season on Lake Trout and Whitefish.

1. Have you actually observed the lamprey parasitic on
Lake Trout? .... How frequently? ....
Whitefish? .... How frequently? ....
Other species? .... How frequently? ....
2. Have you observed the lamprey marks on the surface of the body of
Lake Trout? .... How frequently? ....
Whitefish? .... How frequently? ....
Other species? .... How frequently? ....
3. Have you seen the sea lampreys in streams flowing into
Lake Huron? ....
Georgian Bay? ....
North Channel? ....
for spawning purposes? ....
Were the lampreys numerous or not? ....
Name the streams and their locations in which you have seen this occur ....
4. Have you observed that the sea lamprey dies after spawning? ....

FISH CULTURE BRANCH
Signature and address of Licensed Fisherman
March 7, 1945.

Replies to the questionnaire (not all of them equally useful) were received from 221 or approximately 52 percent of the fishermen to whom they were sent. A summary of the observations on the frequency of occurrence of sea lampreys and on the incidence of marked fish may be found in Tables 3–7.

In all three major sections of the Province of Ontario waters of Lake Huron—Huron proper, Georgian Bay, and North Channel—attacks by sea lampreys appear to be frequent, especially on lake trout. A striking

TABLE 3.—*Summaries of replies to questionnaire on sea lamprey with respect to occurrence of lampreys on fish and frequency of marked fish*

[Received from commercial fisherman of three regions of Lake Huron proper (Ontario waters)]

Region	Species	Lampreys seen on fish			Lamprey marks on fish			Range of estimated percentages of marked fish
		Yes	No	No reply	Yes	No	No reply	
Cockburn Isl. to Fitzwilliam Isl.	Lake trout..	5	1	0	5	1	0	20–70
	Whitefish ..	2	4	0	2	4	0	1–15
	All others..	1	2	3	1	1	4	1– 5
Tobermory to Kincardine	Lake trout..	27	1	0	28	0	0	15–85
	Whitefish ..	2	23	3	2	23	3	1–10
	All others..	5	13	10	5	13	10	1
Goderich to Sarnia	Lake trout..	15	1	2	17	0	1	5–85
	Whitefish ..	4	8	6	6	7	5	1– 5
	All others..	12	2	4	10	2	6	1– 5
All regions combined	Lake trout..	47	3	2	50	1	1	5–85
	Whitefish ..	8	35	9	10	34	8	1–15
	All others..	18	17	17	16	16	20	1– 5

TABLE 4.—*Summary of replies to questionnaire on sea lamprey with respect to occurrence of lampreys on fish and frequency of marked fish*

[Received from commercial fishermen of four regions of Georgian Bay (Lake Huron)]

Region	Species	Lampreys seen on fish			Lamprey marks on fish			Range of estimated percentages of marked fish
		Yes	No	No reply	Yes	No	No reply	
Tobermory to Owen Sound	Lake trout..	18	5	1	21	3	0	5–70
	Whitefish ..	1	14	9	1	14	9	0
	All others..	0	13	11	0	10	14	0
Nottawasaga Bay	Lake trout..	11	5	1	14	3	0	5–75
	Whitefish ..	5	10	2	5	10	2	1– 5
	All others..	3	8	6	4	9	4	1
Christian Isl. to Parry Sound	Lake trout..	12	3	3	14	1	3	1– 5
	Whitefish ..	9	5	4	9	6	3	0
	All others..	9	4	5	5	6	7	0
Point-au-Baril to Manitoulin Isl.	Lake trout..	8	8	0	11	5	0	5–35
	Whitefish ..	0	16	0	1	14	1	0
	All others..	5	8	3	3	9	4	0
All regions combined	Lake trout..	49	21	5	60	12	3	1–75
	Whitefish ..	15	45	15	16	44	15	0– 5
	All others..	17	33	25	12	34	29	0– 1

TABLE 5.—*Summary of replies to questionnaire on sea lamprey with respect to occurrence of lampreys on fish and frequency of marked fish*

[Received from commercial fishermen of two regions of the North Channel (Lake Huron)]

Region	Species	Lampreys seen on fish			Lamprey marks on fish			Range of estimated percentages of marked fish
		Yes	No	No reply	Yes	No	No reply	
North Shore	Lake trout..	9	3	1	12	0	1	10–90
	Whitefish ..	5	5	3	8	3	2	10–20
	All others..	10	3	0	12	1	0	10
South Shore	Lake trout..	9	3	1	11	1	1	10–80
	Whitefish ..	5	7	1	6	5	2	3– 5
	All others..	10	1	2	9	0	4	10–30
Both regions combined	Lake trout..	18	6	2	23	1	2	10–90
	Whitefish ..	10	12	4	14	8	4	3–20
	All others..	20	4	2	21	1	4	10–30

TABLE 6.—*Summary of replies to questionnaire on sea lamprey with respect to occurrence of lampreys on fish and frequency of marked fish*

[Received from commercial fishermen of Lake Huron (Ontario waters)]

Region	Species	Lampreys seen on fish			Lamprey marks on fish			Range of estimated percentages of marked fish
		Yes	No	No reply	Yes	No	No reply	
Lake Huron proper (Table 3)	Lake trout..	47	3	2	50	1	1	5–85
	Whitefish ..	8	35	9	10	34	8	1–15
	All others..	18	17	17	16	16	20	1– 5
Georgian Bay (Table 4)	Lake trout..	49	21	5	60	12	3	1–75
	Whitefish ..	15	45	15	16	44	15	0– 5
	All others..	17	33	25	12	34	29	0– 1
North Channel (Table 5)	Lake trout..	18	6	2	23	1	2	10–90
	Whitefish ..	10	12	4	14	8	4	3–20
	All others..	20	4	2	21	1	4	10–30
All regions combined	Lake trout..	114	30	9	133	14	6	1–90
	Whitefish ..	33	92	28	40	86	27	0–20
	All others..	55	54	44	49	51	53	0–30

feature of the data is that nearly as many fishermen actually saw lampreys on fish as encountered fish bearing scars from previous attacks. Estimates as to the percentage of marked fish varied widely: from 0 to 90 percent for lake trout; from 0 to 20 percent for whitefish; and from 0 to 30 percent for other species.[1] The data varied but little among

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[1] Fishes specifically mentioned under "others" in Lake Huron were: ciscoes *(Leucichthys* spp.); suckers (*Catostomus* spp.); and burbot (*Lota lota*). In Lake Superior they were: suckers; yellow pikeperch (*Stizostedion v. vitreum*); and lake sturgeon (*Acipenser fulvescens*).

TABLE 7.—*Summary of replies to questionnaire on sea lamprey with respect to occurrence of lampreys on fish and frequency of marked fish*

[Received from commercial fishermen of Lake Superior (Ontario waters)]

Region	Species	Lampreys seen on fish			Lamprey marks on fish		
		Yes	No	No reply	Yes	No	No reply
Thunder Bay	Lake trout	1	8	3	5	5	2
	Whitefish	2	9	1	3	7	2
	All others	9	2	1	9	1	2
Algoma	Lake trout	1	2	3	2	0	4
	Whitefish	0	3	3	1	1	4
	All others	4	0	2	2	0	4
Both regions combined	Lake trout	2	10	6	7	5	6
	Whitefish	2	12	4	4	8	6
	All others	13	2	3	11	1	6

the smaller districts within the three major sections except in Georgian Bay (Table 4) where there is some indication that depredations by sea lampreys were more severe in the southwesterly portion than along the east shore.

In response to the inquiry concerning the spawning run, 2 fishermen from Huron proper, 10 from Georgian Bay, and 5 from North Channel stated that they had seen spawning sea lampreys in tributary streams. About half described them as "numerous." Of all fishermen reporting, only four said they had seen lampreys dead after spawning. Observations of fishermen on the spawning activities of sea lampreys must, of course, be accepted with reservations because of the chance of confusing that species with the native lake lamprey.

The 18 replies received from fishermen of eastern Lake Superior (Table 7) leave no doubt that the sea lamprey has become well established in that area. Seemingly, however, the depredations are not as severe as in Lake Huron. (The Lake Superior fishermen offered no estimates of the percentage of marked fish.)

EXPERIMENTAL FISHING OPERATIONS

After studying the information submitted by the fishermen, it was decided to launch the initial experimental fishing operations in the following streams all of which flow into the North Channel: Portlock, MacBess, Livingstone, Desbarats, Little Thessalon, and Lauzon. The purpose of the investigation was: (1) to determine the relative abundance of the sea lampreys in these streams during their spawning period in the spring and early summer; (2) to study the characteristics of the streams used by the lampreys for spawning purposes; and (3) to investigate trapping methods in order to determine the most satisfactory procedure to employ for the purpose of controlling the sea lampreys.

Preparations were made during the winter of 1945 and the early spring of 1946. Portable weirs were constructed similar to those used by the Michigan State Department of Conservation on the Ocqueoc River. The screens used in the weirs were 3 feet deep by 12 feet long, made of ¼-inch-mesh heavy sand screening with the exception of the leads which were ½-inch mesh. The screens were nailed to 2-by-4 wooden frames. The weirs were constructed so that they could catch fish migrating upstream or downstream. Hoop nets of 1-inch mesh, No. 9 thread, 2½ and 3 feet deep also were used.

Desbarats and Portlock Creeks are located approximately 30 miles east, and Little Thessalon River approximately 47 miles east of Sault Ste. Marie. MacBess Creek is 2 miles west, Livingstone Creek 2 miles east, and Lauzon River approximately 30 miles east of Little Thessalon River. Desbarats and Portlock Creeks resemble each other rather closely in length, width, absence of rapids, and lack of stony bottom. MacBess and Livingstone Creeks resemble each other in the infrequency of rapids, limited area of stony bottom, and sluggish flow. MacBess Creek is about 20 feet wide and 3 miles long and Livingstone Creek is 15 feet wide and 4 miles long. The Little Thessalon and Lauzon Rivers are about 60 feet wide, but differ greatly in length and volume of flow.

Table 8 gives information on the kinds of nets used, and the number of suckers and sea lampreys caught on the dates and in the streams specified. The principal results from the experiments and accompanying observations are outlined in the following paragraphs:

1. The total number of sea lampreys caught was 11,463, and of these 11,286 or 98.5 percent were taken in the Little Thessalon River. Insignificant numbers, namely, 99, 22, 11, and 45 were taken from Livingstone, MacBess, Desbarats, and Lauzon streams, respectively. Thus it appears that sea lampreys do not enter all streams to the same extent. The Little Thessalon River is a rapidly moving stream having good volume, rapids, and stony bottom.

2. The sea lampreys on their migration upstream, swam through the deep, turbid water of the Big Thessalon and branched off into the clear water of the Little Thessalon entering the rapids. This behavior confirms the observations of Coventry (1922) who gave the following description of nesting areas in the Humber River: "Downstream nests were not discovered below the rapids at the Old Mill Bridge, below which point the river becomes deep with a muddy bottom for the rest of the course to Lake Ontario, a distance of about two miles." Concerning the spawning area Coventry said further: "Between the weir and the bridge the river averages about 30 yards in width and 2 feet in depth at this season of the year with occasional holes as much as six feet deep. The river bed is composed of clean gravel or shingle interrupted here and there by large flat slabs of solid rock and the stream is broken up by frequent rapids, none steep enough to make real white water, although the larger are difficult enough to wade against." The spawning habits described

(one net in each stream), lampreys were taken with 2½-foot hoop nets,
1-inch mesh, in MacBess and Livingstone Creeks, and with 3-foot hoop nets, 1-inch mesh, in Portlock and Desbarats Creeks (one net in each Creek), and with a weir in Livingstone Creek and Lauzon and Little Thessalon Rivers (two in Little Thessalon River)]

Date	Portlock Creek		Desbarats Creek		MacBess Creek		Livingstone Creek		Little Thessalon River		Lauzon River	
	Suckers	Lampreys	Suckers	Lampreys	Suckers	Lampreys	Suckers	Lampreys	Suckers	Lampreys	Suckers	Lampreys
April 21	–	–	–	–	16	–	16	2	–	–	–	–
do. 22	–	–	125	–	20	–	60	3	–	–	–	–
do. 23	900	–	500	–	64	–	123	1	100	14	–	–
do. 24	115	–	300	–	75	–	88	1	100	29	–	–
do. 25	100	–	250	–	35	–	94	2	200	71	–	–
do. 26	20	–	365	–	8	–	30	–	150	34	–	–
do. 27	–	–	–	–	8	–	16	–	150	46	–	–
do. 28	–	–	–	–	5	–	7	–	–	–	–	–
do. 29	63	–	600	–	16	–	11	–	–	180	–	–
do. 30	–	–	–	–	6	–	16	–	–	946	–	–
May 1	–	–	–	–	20	5	43	–	–	739	200	–
do. 2	175	–	400	3	15	2	57	4	–	821	86	–
do. 3	–	–	–	–	40	2	45	5	–	843	250	–
do. 4	150	–	275	–	20	1	35	6	–	356	275	–
do. 5	–	–	–	3	10	–	30	4	–	155	50	–
do. 6	100	–	–	–	12	–	51	2	–	47	–	–
do. 7	–	–	50	–	8	5	109	0	–	–	125	–
do. 8	50	–	100	3	10	–	–	0	–	22	–	–
do. 9	125	–	50	–	8	–	75	–	–	115	–	2
do. 10	75	–	113	1	5	–	–	–	–	27	–	–
do. 11	40	–	14	1	–	–	–	–	–	22	–	–
do. 12	75	–	10	–	–	–	–	–	–	64	–	–
do. 13	175	–	15	–	–	–	50	–	–	24	–	–
do. 14	30	–	32	–	–	–	–	–	–	36	–	–
do. 15	24	–	12	1	–	–	50	–	–	45	25	–
do. 16	60	–	22	–	–	–	–	11	–	177	20	–
do. 17	35	–	24	–	–	4	–	2	–	129	30	–
do. 18	21	–	17	–	–	–	63	–	–	713	25	–
do. 19	–	–	15	–	–	–	–	5	–	147	–	–
do. 20	51	–	17	–	–	–	–	7	–	421	–	–
do. 21	52	–	14	–	–	–	–	3	–	65	–	–
do. 22	35	–	12	–	–	–	–	5	–	25	–	–
do. 23	37	–	15	–	–	–	–	1	–	907	–	–
do. 24	45	–	19	–	–	–	–	5	–	154	–	–
do. 25	10	–	12	–	–	–	–	–	–	45	–	3
do. 26	7	–	7	–	–	–	–	–	–	–	–	–
do. 27	–	–	30	–	–	–	–	–	–	–	–	5
do. 28	66	–	24	–	–	–	–	–	–	30	–	–
do. 29	35	–	15	–	–	–	–	–	–	–	–	7
do. 30	25	–	22	–	–	–	–	–	–	382	–	5
do. 31	–	–	12	–	–	1	–	12	–	239	–	5
June 1	25	–	20	–	–	–	–	6	–	16	–	6
do. 2	15	–	15	–	–	–	–	4	–	41	–	3
do. 3	12	–	–	–	–	1	–	2	–	18	–	3
do. 4	–	–	–	–	–	–	–	2	–	44	–	3
do. 5	–	–	–	–	–	1	–	4	–	100	–	–
do. 6	–	–	–	–	–	–	–	–	–	422	–	–
do. 7	–	–	–	–	–	–	–	–	–	1657	–	–
do. 8	–	–	–	–	–	–	–	–	–	167	–	–
do. 9	–	–	–	–	–	–	–	–	–	569	–	–
do. 10	–	–	–	–	–	–	–	–	–	168		

by Coventry as follows were also confirmed: "Nests were excavated only in the more rapid regions and indeed only in the shallower parts of these. The majority were in not more than a foot of water, and none were seen at a greater depth than 2 feet."

3. The sea lampreys entered the weir at nightfall; from 2 a.m. to 3 a.m. lampreys were taken out of the weirs in large numbers. The largest haul was made on the night of April 30, 1946, when 946 lampreys were taken out of one weir in the Little Thessalon.

4. Hoop nets were not effective, because the lampreys put their tails through the mesh and wriggled out.

5. At first, when the weirs had no screening on the bottoms of the traps, sea lampreys burrowed underneath and escaped. When screening was placed on the bottoms of the traps there was no more trouble of this nature. It was found necessary to put a skirt along the bottom of the lead and to bury it in the gravel, to prevent their escaping.

6. When the weirs were made up the tunnel was 4 inches square and 8 inches above the bottom. This arrangement was not satisfactory. Stones and gravel were heaped up to the level of the tunnel entrance, but the lampreys did not enter in numbers. Finally, when the gravel and stones were removed and a 2-inch hole was bored, making a new tunnel as close to the bottom as possible, no further trouble was experienced.

7. On June 17 during a heavy rainstorm the water rose 6 inches above the tops of the weirs in all the streams. This freshet permitted the sea lampreys to pass beyond the weir into the rapids. When the water subsided they were caught in large number (1,657) at the foot of the falls.

8. One of our field officers reported that cold weather and storms cause the sea lampreys to disappear during the spawning run.

9. Of the 11,463 sea lampreys taken, approximately 25 were small. The larger specimens ranged from 18 inches to 30 inches long, the majority being about 24 inches long.

10. In order to prove that the sea lampreys were not moving upstream and remaining in an area below the weir, where rapids and stony bottom occurred, a second weir was placed a quarter-mile below the first.

11. Of 10 tons of suckers caught, 75 percent had lamprey marks on them.

12. When the hoop nets were first set an odd bullhead was taken, but only suckers and sea lampreys later.

13. As the sea lampreys increased the suckers decreased. The latter appeared to react against moving into waters with lampreys; below the weirs suckers were abundant. It was reported that in other years when lampreys were not as abundant the suckers moved farther upstream. During the past 7 years lampreys have appeared to be increasing in the Thessalon River.

During the field operations there was no conclusive evidence of mortality of sea lampreys. Coventry (1922) stated, "as to whether the parents die after spawning I cannot make a definite statement. I have however a strong feeling that they do not, and this opinion is based on the very small number of dead lampreys as compared with the abundance of the living seen during the nesting season. . . . If, then, the parents die at the end of the breeding season, they appear to return first to the lake, for it is hardly imaginable that so many individuals dying in so short a space of time and in so limited an extent of water should leave so slight a trace of the event." On the other hand Gage (1928) has cited good evidence to show that lampreys die after spawning.

RECOMMENDATIONS ON CONTROL METHODS AND ON FURTHER INVESTIGATIONS

1. One-half-inch mesh in the weirs is better than ¼-inch mesh. The former mesh does not clog with debris so easily.

2. The earlier the equipment is set the better. Sea lampreys were caught during the early period of the sucker run, and it is obvious that for effective control the lampreys should be caught before they spawn.

3. Metal weirs rather than hoop nets are essential to successful operation. Leaves and other debris can be removed from the metal mesh with much greater effectiveness than from hoop-net mesh.

4. The wings of the weirs should be 5 feet deep instead of 3 feet to avoid the possibility of an overflow during periods of heavy rainfall.

5. Utilization of the sea lamprey as food should be investigated. Fresh sea lamprey packed in ice were sent to a Canadian packing plant and canned. The edibility of the product was reported to be satisfactory. A great deal more experimentation in this direction is necessary before specific methods of utilization can be recommended.

6. Since Lake Ontario may be a potential source of supply of sea lampreys for the upper Great Lakes, the experiment which aims at control should be extended to include Lake Ontario.

7. An intensive study of the life history of the sea lamprey in the Great Lakes, of its centers of abundance, and of the characteristics of the streams in which it breeds, might conceivably give information on which to base more intelligent control.

8. Methods of capture should be studied with a view to improvement.

9. The extent of scarring of lake trout and other commercial varieties, and the effect of these marks on the commercial value of the fish should be investigated.

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A BRIEF HISTORY OF THE SEA LAMPREY PROBLEM IN MICHIGAN WATERS[1]

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Abstract

The life history of the sea lamprey is briefly outlined. Mature adults are anadromous, spawning chiefly in May and June and dying shortly thereafter. The larvae pass 4 to 5 years in the sand, gravel, and silt banks of the spawning stream before transforming into the parasitic stage. After becoming fitted for a parasitic life, they live as free-swimming adults, parasitic on fish, from 1½ to 3½ years before becoming sexually mature and ready to spawn and die.

The sea lamprey spread into the upper Great Lakes within the period 1921–1936, and is firmly established in Lakes Erie, Huron, Michigan, and Superior, and possibly in some of the larger inland lakes.

Experiments of 1944 and 1945 on the Ocqueoc River in northeastern Michigan involving the operation of a sea lamprey trap were described. Although the trap failed to take a portion of the run each year, 3,366 lampreys were destroyed in 1944 and 4,608 lampreys were caught and killed in 1945.

Most of the upstream movement (95 percent or more) occurred between the hours of midnight and noon and over half took place between midnight and 6:00 a.m. The total length of the Ocqueoc River sea lampreys ranged from 14.1 inches to 30 inches. Males appeared to precede the females to the spawning grounds. The peak of the run came when the average daily water temperature was from 51° to 60° F.

Conservation officers of the Michigan Department of Conservation in all counties bordering the Great Lakes questioned commercial fishermen during June and July 1946 concerning the sea lamprey problem. Their records indicated that: (a) sixty-eight spawning streams or areas were reported; (b) depending on the locality fished and the species of fish sought, from 0 to 100 percent of the catch was lamprey-scarred. Lake trout were most affected, followed by whitefish, suckers, yellow pikeperch, and carp; commercial fishermen, except those fishing from ports in northern Lake Michigan and northern Lake Huron, suffered almost no loss due to scarring of fish by sea lampreys (in the affected areas, the loss was reported to vary from 5 to 75 percent of the normal value of the fish).

Any program for the eradication of sea lampreys through attempts to block off and trap all lamprey spawning runs would be exceedingly costly but the operation of traps on the more important spawning streams might control the pest.

Further research on the life history and possible economic utilization of the sea lamprey is suggested.

Introduction

The sea lamprey (*Petromyzon marinus*), like the smelt (*Osmerus mordax*), originally existed during adult life in marine waters, and returned to fresh-water streams only to reproduce. That it is a very adaptable form is demonstrated by the present distribution in several inland lakes of New York and Michigan, and in all the Great Lakes.[2]

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[1] Contribution from the Institute for Fisheries Research.

The sea lamprey of the smaller inland lakes is considered by Hubbs and Pope (1937) to be a dwarf form of the marine species, as it seldom exceeds 15 inches in total length when mature. Gage (1893) gave total length measurements of mature ocean-run lampreys from Massachusetts which averaged about 26 inches, whereas the "lake" form studied by him in New York averaged 12.6 inches. Michigan specimens of the sea lamprey range in size from 12.5 inches to 30.0 inches, and individuals as large as 40 inches in total length have been reported by commercial fishermen. With the exception of the size differences noted, it appears that the form now present in all the waters mentioned is identical.

Previous workers (Hubbs and Lagler, 1941) have published taxonomic keys which aid in separating the sea lamprey from the four other species of lampreys present in Michigan waters. The life history of the "lake" form of the sea lamprey has been minutely described by Gage (1893, 1928).

The present paper contains a brief account of the life cycle of the sea lamprey, the known history of its spread into Michigan waters, observations on certain spawning runs in Michigan streams, and a discussion of control measures, as well as the results of interviews by conservation officers with commercial fishermen. The implications of control and eradication procedures suggested by interested parties are also discussed.

LIFE HISTORY

The important details of the life history of the sea lamprey in Michigan are as follows:

The mature adults migrate into running water between April and August. The peak of the spawning run occurs after the water temperature reaches 50° F., usually in late May and early June.

After eggs are laid in specially prepared nests on gravel or rubble riffles in 4 to 36 inches of water, the adults die.[3]

Within 3 weeks, the viable eggs develop into larval lampreys called ammocoetes. This stage corresponds roughly to the tadpole stage of the frog or toad which differs greatly from the adult in morphological structure and mode of life.

The nonparasitic ammocoetes live for 4 to 5 years in sand and mud banks in the vicinity (usually slightly downstream) of the spawning site.

When a length of 6 to 8 inches has been attained, the larva meta-

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[2] Only recently has the sea lamprey penetrated into Lake Superior.

[3] This point still seems to be held in some doubt by various investigators and numerous commercial fishermen. However, the evidence on the matter, as presented by Gage (1928, pp. 169–171) strongly supports the conclusion that the adult sea lamprey dies after spawning is completed.

On June 26, 1945, after spawning had passed its peak on the Ocqueoc River about half (52 of 107) of the sea lampreys seen were dead or dying. Many, in an advanced state of decomposition, were lodged on the edges of the pools out of the current. Others had been caught on overhanging branches, and some were barely able to wriggle from the author's grasp.

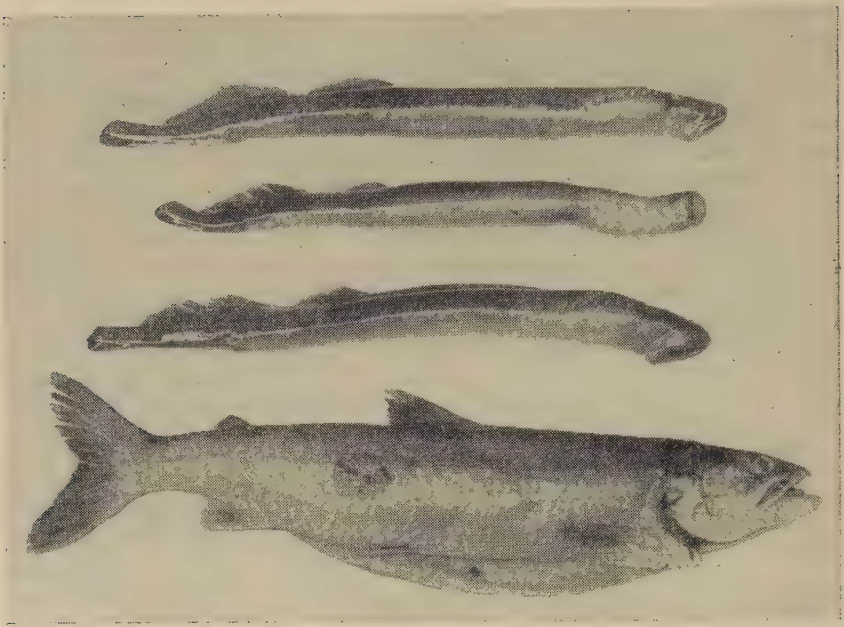

FIGURE 1.—Sea lampreys, and lake trout showing characteristic healed scar. (Photo by Michigan Department of Conservation).

morphoses and takes on morphological characters which fit it for parasitic life, including horny teeth, a rasping tongue, and functional anti-coagulant-secreting buccal glands. It remains in the sand and mud banks during this transformation.

After metamorphosis is completed, the transformed sea lampreys migrate into the larger inland lakes or the Great Lakes. Here their food consists of the blood (and to a small extent the flesh) of fishes. Their parasitic life was thought by Gage (1928) to last from 1½ to 3½ years. On reaching maturity the adults return to flowing streams to reproduce and die. Although the evidence given in the literature is of an indirect nature, it appears that the duration of the life cycle is no less than 5 years and possibly as long as 8 years.

The parasitic stage of the life cycle has caused great concern in recent years, particularly since the sea lampreys have increased in Lakes Huron and Michigan, and more and more of the choice marketable species of Great Lakes fish are found scarred, wounded, or dead. This large parasite attaches itself to the host fish at any convenient point, by means of the oral sucking disc. The horny circumoral teeth aid in penetrating the scales, and the finely-toothed tongue drills a hole in the flesh. If a blood vessel is not found immediately, the position of the oral disc can be shifted without loss of its hold until blood is found. Once the blood flow is started the secretion of the buccal glands prevents coagulation. The parasite then holds to the fish until death of the host or satiation of the lamprey occurs. Gage (1928, p. 185) made the following statements, based on experiments with sea lampreys (the dwarfed New York State form) and bullheads in confinement: " . . . if the fish was relatively large, the lamprey does not usually kill it, but if the fish is small, the lamprey may kill it. Several examples with large and with small fish showed this over and over."

From these experiments he concluded also that about 1 meal every 36 days was the usual rate of feeding, and that the sea lamprey (of the sizes he studied) took about 1 ounce of blood per feeding.

The end results on fish which have suffered sea lamprey attacks vary from completely healed, scaled-over scars about the size of a 25-cent coin (Fig. 1) which are rather inconspicuous, to specimens which have been observed with as high as nine fresh, livid wounds, some of them through the entire flesh of the body wall. Fish attacked shortly before being captured in the nets of commercial fishermen are usually paler than undamaged specimens in the same catch.

Spread of the Sea Lamprey into Michigan Waters

Prior to 1921, the sea lamprey had penetrated only as far as Lake Ontario, where it had existed as the dwarfed form already mentioned. In that year, Dymond (1922) reported the capture of specimens of the sea lamprey at Merlin, Ontario, in central Lake Erie.[4] The spread thereafter was as follows: 1927, near West Sister Isand (Osborn, Wickliff and Trautman, 1930); 1927, near Sandusky, American shore (Hubbs and Brown, 1929); 1928, near Rondeau, Canadian shore (Hubbs and Brown, 1929); 1930, St. Clair River, Michigan (Hubbs and Pope, 1937); 1932, Huron River, Michigan, from spawning run (Creaser, 1932); 1934, Swan Creek, Ohio, spawning run (Hubbs and Pope, 1937); 1936, 15 miles east of Milwaukee, Wisconsin (Hubbs and Pope, 1937); Elk Rapids, Michigan (Hubbs and Pope, 1937); 1937, Ocqueoc River, Michigan (Conservation Officer Marvin Norton's semi-monthly report).

Since that time the author has observed sea lamprey spawning runs in the Clinton River (1938), the Au Gres River (1941), the Platte River (1943), the Ocqueoc River (1944), and the Rifle River (1944). They are reported to run in great numbers in the Cheboygan River. Other streams where the sea lampreys were reported to spawn during the spring of 1946 were located in 26 of the 41 Michigan counties bordering on Great Lakes waters. It is obvious that the sea lamprey has penetrated to and become well established in the Great Lakes waters of Michigan.

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[4] A. E. Crewe also captured a specimen in the same year and at the same locality according to Gage (1928).

RESEARCH ON SEA LAMPREY CONTROL IN MICHIGAN

In May 1938, Conservation Officer Earl Goff reported a run of spawning sea lampreys in the Clinton River, a tributary of Lake St. Clair in the vicinity of Yates' Cider Mill, near Rochester, Michigan. A similar run occurred there in 1939. Trautman and Deason (MS)[5] and Deason[6] made observations on these runs and on the spawning activities. Interviews with Harry Yates of Rochester, Michigan, indicated that sea lampreys were first observed in that locality in 1934, had returned yearly thereafter in slightly increasing numbers, and were reported to spawn in a rather limited riffle area about a half-mile below a dam with a 4-foot head. In 1938, four specimens were captured which ranged from 14.2 inches to 17.4 inches in length. A search for eggs and ammocoetes was unsuccessful, except that one egg was observed attached to a stone in a nest where spawning took place. In the 1938 report (see Footnote 5) five methods of manual control were suggested: by hand, minnow seine, long-handled knife, spear, and gaff. Plans for the construction of the last three items were given. Recommendations were made for investigation of other spawning areas, and the 1939 report (see Footnote 6) recommended the construction of an experimental weir in conjunction with Mr. Yates' water wheel as the most likely means of controlling the Clinton River run.

In March 1944, a cooperative plan for an experimental study of methods for controlling the sea lampreys in the Ocqueoc River was drawn up by representatives of the East Presque Isle Sportmen's Club, the Field Administration Division, and the Fish Division of the Michigan Department of Conservation. The club contributed materials and labor to erect a weir, while the Conservation Department paid the salary of a weir attendant. A weir was installed about 2½ miles upstream from Lake Huron, just below the outlet of Ocqueoc Lake. Here the river has steep banks approximately 35 feet high, a width of about 50 feet, and a depth which does not exceed 2 feet. The bottom is hard clay and rubble with a surface covering of gravel and clam shells.

The weir was of the conventional "double-V" type with the traps in midcurrent. Material for the structure, donated by the Michigan Limestone and Chemical Company of Rogers City, consisted of used stone screenings. These screens were 15 feet long by 3 feet wide, and were of ¾-inch or 1-inch mesh. These sections were overlapped about 1 foot to form the blocking arms, and were supported by and wired to steel fence stakes, driven firmly into the bottom. Irregularities in the bottom were filled with gravel and rubble to form a tight seal.

The trap sections were prefabricated in a single unit from the used screening and were approximately 6 by 8 by 3 feet. A funnel-type lead-in sloped up from the mouth on the bottom side. In 1945, ¼-inch-mesh hardware cloth was used to line the downstream blocking arms and the trap, and to make an overhanging apron on these parts of the weir. This addition was prompted by the observation that many small lampreys were able to "tail" through the ¾-inch mesh, and that the larger ones might "jump and fall" over the blocking arms when the water level was high.

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[5] Trautman, Milton B., and Hilary J. Deason, 1938. Observation of the spawning of the sea lamprey (*Petromyzon marinus*) in the Clinton River, Oakland and Macomb Counties, Michigan, with suggestions for control. (Unpublished MS).

[6] Deason, Hilary J., 1939. A second report on observations of the sea lamprey, *Petromyzon marinus*, in the Clinton River, Oakland and Macomb Counties, Michigan. (Unpublished MS).

In 1944, the weir was operated between May 22 and July 24. A total of 3,366 lampreys was destroyed as follows: May, 2,000; June, 1,225; July, 141. Daily catch records were not kept. The mesh size of the blocking arms and trap was too large, the weir was over-topped on several occasions, and undercut at several points. Hundreds of spawning sea lampreys were observed to reach the spawning grounds below Ocqueoc Falls.

The weir was re-installed at the same point on April 22, 1945, and was removed from the stream on July 16. Trap records and temperature data were kept more accurately in 1945, but, as in 1944, the weir did not completely block the run. The blocking arms were undercut because they were not sealed by sheet-piling, and high water caused by heavy rains completely overtopped the 3-foot sections during the periods April 25–28, and May 28–June 6. After the last period, spawning sea lampreys increased very noticeably on the riffles below Ocqueoc Falls, several miles above the weir site.

In 1945, the traps caught 9,911 individuals (Table 1). All were upstream migrants except 29 sea lampreys and 1 rainbow trout taken in the downstream trap. The total was made up of 4 species of lampreys, 15 species of fresh-water fish, 2 turtles, and 5 water snakes. The four species of lampreys trapped were the sea lamprey, and the silver lamprey (*Ichthyomyzon unicuspis*), both of which are parasitic on fish in Lake Huron, the Michigan brook lamprey (*Ichthyomyzon fossor*), and the American brook lamprey (*Entosphenus lamottenii*). The latter two species are both non-parasitic. The weir attendant, who dipped the lampreys chiefly at night and destroyed them after passing on the game fish and rough fish, was not able to distinguish among the species of lampreys, so the exact numbers of each species present cannot be stated. Observations on the spawning beds, however, indicated that 90 percent or more of the run was composed of sea lampreys. A total of 4,608 lampreys was trapped and destroyed.

The species of fish and the numbers of each taken in the traps were as follows: common sucker (*Catostomus c. commersonnii*), 1,555; redhorse (*Moxostoma aureolum*), 649; rainbow trout (*Salmo gairdnerii irideus*), 10; brook trout (*Salvelinus f. fontinalis*), 3; yellow pikeperch (*Stizostedion v. vitreum*), 6; northern pike (*Esox lucius*), 1; yellow perch (*Perca flavescens*) fingerlings, 1,586; smallmouth black bass (*Micropterus d. dolomieu*), 250; common shiner (*Notropis cornutus frontalis*), 857;

Table 1.—*Trap catch at the Ocqueoc Weir, season of 1945.*

[Figures in parentheses are numbers of individuals taken in downstream traps. The peak run for each species is shown in italics]

Species	Period						Total	Size range[1]
	April 22–April 30	May 1–May 15	May 16–May 31	June 1–June 15	June 16–June 30	July 1–July 15		
Sea lamprey[2]	9	893	*2,688*	491	460 (18)	67 (11)	4,608 (29)	8–30 inches
Common sucker	*1,196*	174	74	79	21	11	1,555	14–20 do.
Red horse	309	*340*	...	...	...	...	649	14–20 do.
Rainbow trout	...	...	*9*	...	...	1 (1)	10 (1)	18–30 do.
Brook trout	...	1	...	...	...	*2*	3	...
Yellow pikeperch	1	2	*3*	...	...	...	6	2– 5 pounds
Northern pike	...	1	...	...	...	...	1	...
Yellow perch	...	*1,450*	114	22	...	...	1,586	3– 6 inches
Smallmouth bass	2	20	*99*	25	96	8	250	4– 7 do.
Common shiner	...	243	50	132	*372*	40	837	4– 8 do.
Carp	...	2	3	3	3	*6*	17	3– 8 pounds
Dogfish	...	...	1	1	...	...	2	3– 5 do.
Rock bass	...	*22*	...	6	13	3	44	4– 8 inches
Bullhead	...	...	1	29	27	*50*	107	5–10 do.
Smelt	3	...	...	...	...	...	3	...
Creek chubs	...	...	...	82	*144*	...	226	4– 7 inches
Turtle	...	...	...	...	...	*2*	2	...
Water snake	...	...	...	...	...	*5*	5	...
Total	1,520	3,148	3,042	870	1,136 (18)	195 (12)	9,911 (30)	...

[1] Only sea lampreys and rainbow trout were actually measured. All other sizes were estimated.

[2] Some American, Michigan brook, and silver lampreys are included in the catch records.

carp (*Cyprinus carpio*), 17; dogfish (*Amia calva*), 2; rock bass (*Ambloplites rupestris*), 44; bullhead (sp. ?), 107; smelt *Osmerus mordax*), 3; creek chub (*Semotilus a. atromaculatus*), 226. The identity of the turtles is not known; the water snakes were *Natrix s. sipedon*.

The daily trap catches of lampreys, the average daily water temperature, the water level and the average size of the lampreys trapped are given in Table 2. The numbers of lampreys moving from midnight–6 a.m., 6 a.m.–noon, noon–6 p.m., and 6 p.m.–midnight of each day are listed also for the period May 4–June 30. It may be concluded that 95 per cent or more of the migrants moved between the hours of midnight and noon and that slightly more than half of the movement occurred between midnight and 6 a.m. The hours of greatest activity were during complete darkness.

The length of mature sea lampreys in the Ocqueoc River varied from 14.1 inches to 30 inches. Eighteen females taken during the first 10 days of July ranged in size from 14.1 to 21.7 inches with an average length of 17.9 inches. Twelve males taken at the same time varied from 15.5 to 19.6 inches and averaged 17.6 inches in total length. Sea lampreys entering the Ocqueoc River appear to be larger than those described by Gage (1928) for New York, but smaller than those commonly running from the Atlantic Ocean.

From examinations on May 19 and 20 (before the peak of the run) and on June 15 (after the peak) of a limited number of specimens by the weir attendant, the sex ratio was determined to be 70 percent males to 30 percent females before the peak, and 80 percent females to 20 percent males after the peak had passed. It might be inferred from this fact that the males run somewhat earlier than the females.

Comparison of water temperature and the number of lampreys trapped each day reveals an increase in the run as the temperature approaches 50°–60° F. (Fig. 2). Slightly more than 53 percent of the total upstream migrants trapped (2,452 of 4,579) were taken in the period May 19–28 when the average daily water temperatures ranged from 51.0° to 60.5° F. Sea lampreys were taken by the trap every day it was in place and could be examined. Average daily water temperatures ranged from a low of 42° to a high of 72° F. during the period of operation.

Observations on the spawning grounds below Ocqueoc Falls about 10 miles upstream from the weir, in both 1944 and 1945, indicated that numerous mature individuals were escaping the traps and reproducing. Some of these mature lampreys may have been resident in Ocqueoc Lake above the weir since it did appear that the weir was fairly efficient in 1945 until overtopped by flood waters during the period May 28–June 6.

Present Effect of the Sea Lamprey on the Great Lakes Fishery

In an effort to gain more information which might be useful in controlling the sea lamprey, the conservation officers of the Division of Field

TABLE 2.—*Daily catch of sea lampreys,*[1] *and data on water temperature and water level at Ocqueoc weir, 1945.* Figures in parentheses indicate numbers of downstream migrants trapped

Date	Number of sea lampreys trapped between				Daily total	Average daily water temperature F°	Water level (inches above or below normal)	Average size or size range of lampreys (inches)
	Midnight-6 a.m.	6 a.m.–noon	Noon–6 p.m.	6 p.m.–midnight				
April 22	...	...	...	...	1	42	...	30
23	...	...	...	...	1	42	...	24
24	...	...	...	...	...	42	...	...
25	...	...	...	...	1	44	+14	7
26	...	...	...	...	...	42	+12	...
27	...	...	...	...	...	43	+10	...
28	...	...	...	...	...	43	+ 8	...
29	...	...	...	...	2	43	+ 6	...
30	...	...	...	...	4	43	+ 7	...
April totals	...	...	...	...	9	...	...	...
May 1	...	...	...	...	11	43	+ 3	...
2	...	...	...	...	33	44	+ 2	...
3	...	...	...	...	43	45	+ 1	20
4	...	11	...	51	62	46	Normal	21
5	31	23	...	...	54	47	Normal	...
6	73	55	3	...	131	50	Normal	...
7	43	30	4	4	81	50	— 1	...
8	56	40	...	...	96	48.5	+ 6	...
9	37	41	...	...	78	44.5	+ 8	...
10	27	33	...	...	60	46	+ 7	...
11	27	17	...	...	44	46	+ 5	...
12	29	17	...	...	46	45	+ 5	...
13	...	21	...	34	55	46	+ 5	...
14	31	6	...	1	38	46	+ 5	...
15	...	38	23	...	61	47	+ 4	...
16	43	37	...	...	80	48	+ 5	16–26
17	47	28	...	...	75	48	+ 4	24
18	52	29	...	...	81	48	+ 4	...
19	172	40	...	...	212	51	+ 3	14–26
20	42	186	...	...	228	52	— 1	14–26
21	200	141	...	...	341	52	— 1	14–21
22	186	71	...	...	257	58	— 2	12–26
23	212	76	...	...	288	56	+ 2.5	12–26
24	20	105	...	...	125	52.5	+ 2	...
25	46	142	...	...	188	57	+ 2	14–20
26	177	108	...	...	285	58	+ 2	...
27	105	186	...	...	291	59	+ 3	12–26
28	163	74	...	...	237	60.5	+ 7	14–24
29	...	...	...	...	...	62	+ 9	...
30	...	...	...	...	...	60	+16	...
31	...	...	...	...	...	60	+14	...
May totals	1,819	1,555	30	90	[illegible]			

Date	Midnight-6 a.m.	6 a.m.–noon	Noon–6 p.m.	6 p.m.–midnight	Total	F°	normal)	(inches)
June 1	...	...	...	...	...	60	+10	...
2	...	...	...	...	...	55	+10	...
3	...	...	...	...	...	50.8	+ 9	...
4	...	...	...	...	...	50	+ 7	...
5	...	...	...	...	...	48	+ 8	...
6	6	63	...	...	69	48	+ 8	12–20
7	74	35	...	...	109	50.8	+ 6	...
8	46	6	...	...	52	52.5	+ 4	...
9	39	40	...	...	79	56.5	+ 3	12–18
10	8	1	...	...	9	60	+ 2	...
11	21	...	...	...	21	61	+ 5	18
12	12	11	...	...	23	60	+ 4	...
13	21	17	...	...	38	62	+ 3	20
14	28	21	...	...	49	62	+ 3	24
15	14	28	...	...	42	62	+ 6	22
16	21	20	...	...	41	62	+ 7	22
17	17	21	...	...	38	63	+ 8	22
18	26	21	...	...	47	64	+ 8	12–24
19	26	11	...	...	37	64	+ 6	22
20	7	1	...	...	8	66	+ 4	...
21	17	29	...	...	46	66	+ 3	...
22	6	32(8)	...	...	38(8)	66	+ 3	...
23	18	17(2)	...	...	35(2)	66	+ 3	...
24	17	11	...	3(3)	31(3)	68	Normal	...
25	23	14(2)	...	...	37(2)	68.5	Normal	22
26	13	...	11	...	24	69	Normal	...
27	16	...	11	...	27	69	Normal	...
28	16	...	1(1)	...	17(1)	70	Normal	...
29	17	...	2(2)	...	19(2)	70	Normal	...
30	11	...	4	...	15	70	Normal	...
June totals	520	399(12)	29(3)	3(3)	951(18)	...	...	...
July 1	3	...	3(1)	...	6(1)	70	+ 2	...
2	12	...	...	...	12	69.5	+ 2	...
3	6	...	...	...	6	71	+ 2	...
4	8	...	...	...	8	71	+ 2	...
5	7(1)	...	...	...	7(1)	71.5	+ 1	...
6	8(5)	...	...	...	8(5)	72	Normal	10–18
7	1	...	...	...	1	72	Normal	20
8	3	...	...	...	3	72	Normal	16
9	3	...	...	...	3	70	Normal	18
10	1	...	...	...	1	68	+ 2	...
11	3	...	...	...	3	68	Normal	...
12	1	...	...	...	1	64	Normal	...
13	3(2)	...	...	...	3(2)	64	Normal	...
14	3(1)	...	...	...	3(1)	64	Normal	...
15	2(1)	...	...	...	2(1)	65	Normal	...
July totals	...	...	...	...	67(11)	...	...	...
Grand								

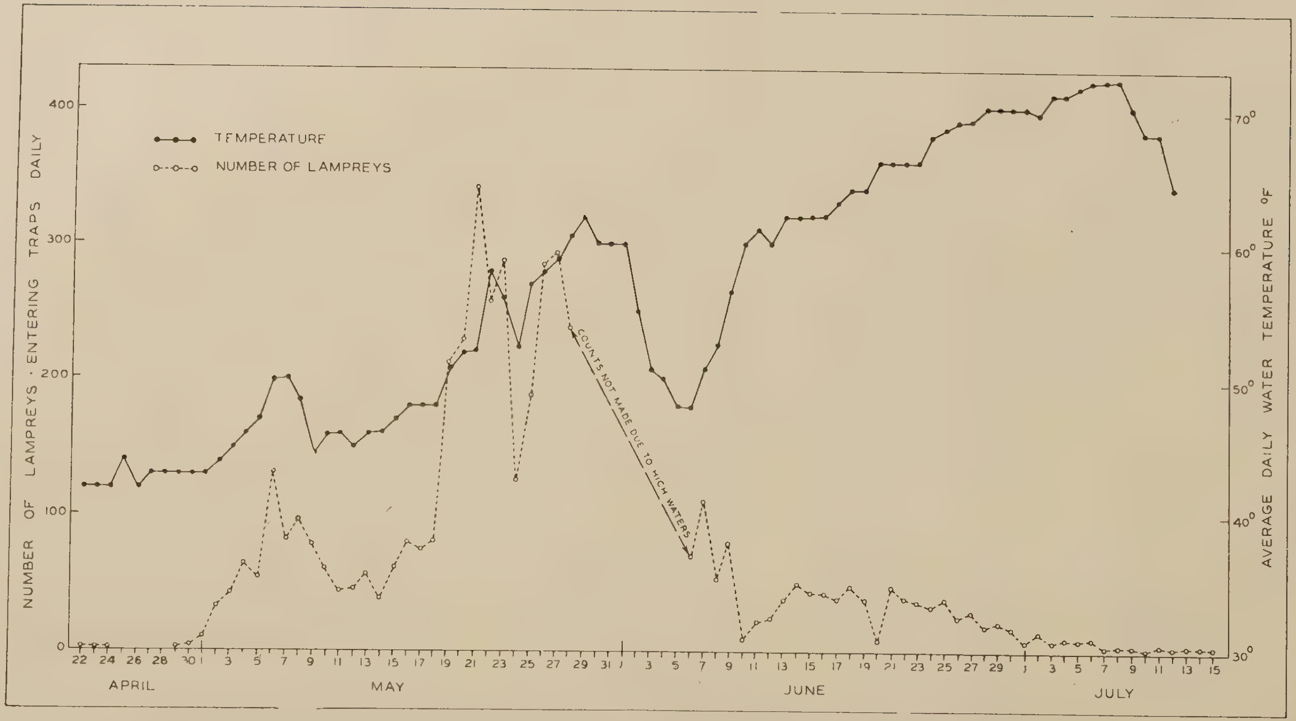

FIGURE 2.—Daily water temperature and catch of lampreys, Ocqueoc River weir, 1945.

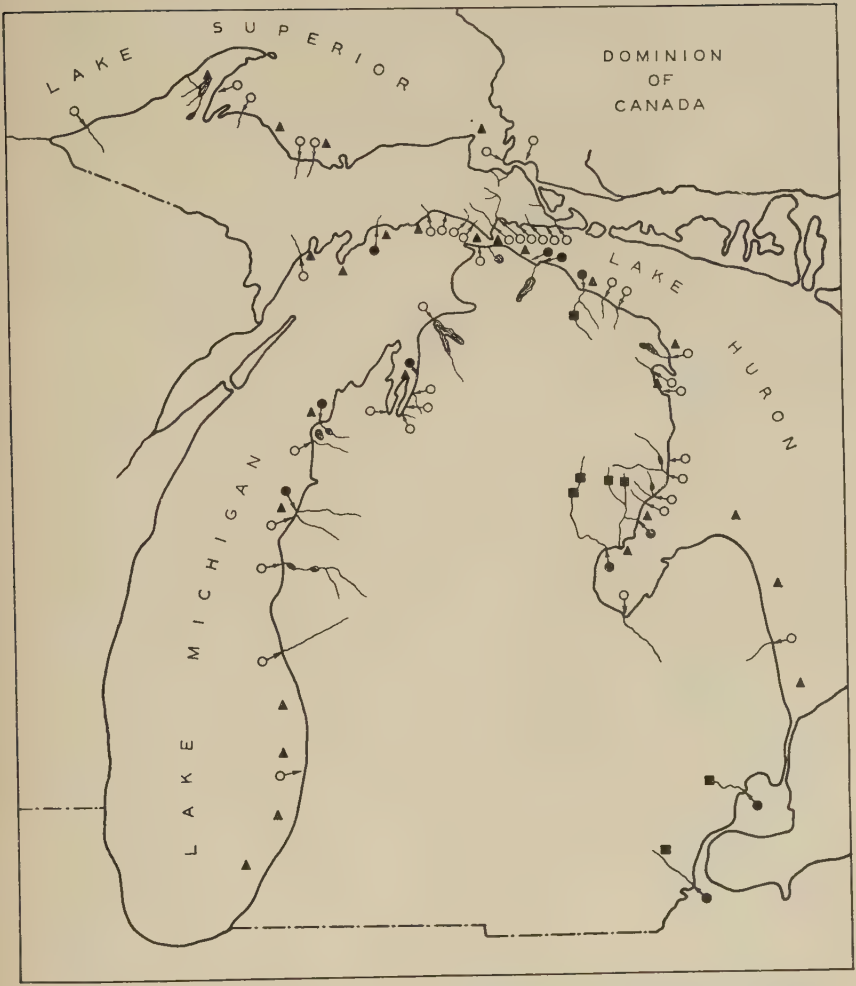

FIGURE 3.—Map of Michigan showing distribution of the sea lamprey as reported by employees of the Michigan Department of Conservation and by commercial fishermen. Streams shown are those where migrations of adult lampreys were noted by departmental field employees. Solid circles with arrow = sea lamprey spawning runs verified by Fish Division personnel, 1932–1946; open circles with arrow = sea lamprey spawning runs reported by conservation officers, 1946; solid squares = sea lamprey spawning sites observed by Fish Division personnel or other technical workers; solid triangles = fishing ports or fishing grounds where commercial fishermen have reported lamprey damage.

TABLE 3.—*Summary of conservation officers' reports on sea lamprey spawning streams, the percentage of scarred or wounded fish taken in commercial gear, and the effect of scars on marketability, for Michigan waters of the Great Lakes, June, 1946*

Lake	Number of officers reporting	Spawning streams reported	Percentage of commercial catches reported scarred[1]		Species affected	Reports on marketability of scarred fish		
			Range	Average less than		Number making no report of loss	Number reporting no loss	Number reporting some loss
Superior	15	13	0–10	1	Lake trout	3	10	2 reported scarred fish difficult to sell or unmarketable.
Michigan (Northern half)	21	30	0–100	50	Lake trout Whitefish Suckers	7	6	8 reported 5 to 75 per cent loss on scarred fish
Michigan (Southern half)	5	2	30–90	60	Lake trout	. . .	4	1 reported most fish salable, half-price for scarred fish.
Huron (Northern half)	6	17	0–100	50	Lake trout Whitefish Suckers	2	. . .	4 reported 5 to 75 per cent loss on fresh, wounded fish, no loss on fish with healed scars.
Huron (Saginaw Bay)	3	2	1	1	Yellow pikeperch Sucker Carp	. . .	3	. . . .
Huron (Southern half)	4	2	1–95	50	Lake trout Whitefish Yellow perch Suckers	1	3	. . . .
Erie and St. Clair	5	2	1–80	20	Whitefish Carp Unstated	. . .	5	. . . .
Totals	59	68	0–100	31	. . . .	13	31	15

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[1] Determined by averaging maximum percentages given for all species from all reports. This average is unsatisfactory in that its value depends to a considerable extent on the number of species attacked in addition to the heavily parasitized lake trout. Unfortunately the nature of the original data did not permit more exacting treatment.

Administration in the counties bordering the Great Lakes were instructed in June, 1946, to interview commercial fishermen and report on the following points: (1) number of known spawning streams, (2) percent of total fish taken that are scarred, and (3) the effect of scars on the marketability of the fish. Results of interviews with commercial fishermen were summarized for seven geographical areas of Michigan waters (Table 3).

The sea lamprey is now present in all the Great Lakes. Judging from the conservation officers' reports, the greatest number of spawning streams are tributaries of northern Lake Huron (17) and northern Lake Michigan (30). Locations of the 68 reported spawning streams are given on the map in Figure 3.

The percentage of the commercial catch that was reported to be scarred or marked by sea lampreys varied considerably between the geographical areas and within the several areas. Owing to the extremely wide variation in range of damage reported a statistically accurate estimate of the percentage of fish bearing lamprey marks cannot be obtained from these data. For example, a fisherman might report that during a given period from 10 to 100 percent of the fish in his catches were marked. Without knowing the number and percentage of marked fish in each catch, and the total number of catches, one cannot be sure whether the overall average for the period would be midway of the range reported, or closer to its upper or lower limits.

In the Michigan waters of Lake Superior, up to 10 percent of the lake trout were reported to be scarred, with the average less than 1 per cent. Of the 15 reports, 10 indicated no loss in marketability of scarred fish and 2 that scarred fish were difficult to sell or unmarketable. Three reports did not discuss effects of scars on sales value. The economic loss to the Lake Superior fishermen so far has been of minor consequence.

In both northern Lake Michigan and northern Lake Huron, from 0 to 100 percent of the lake trout were reported as scarred, and up to 10 percent of the whitefish and suckers, or an average (see Footnote to Table 3) of less than 50 percent. Of 27 reports from these waters, 9 contained no mention of any effect on sales, 6 showed that marketability was not affected by the lamprey scars, and 12 indicated 5 to 75 percent loss on scarred fish.

In the southern portions of Lakes Michigan and Huron, the average percentage of commercial species marked by the sea lamprey appeared to be between 50 and 60 percent. Lake trout were the chief victims, but whitefish, suckers, and yellow perch were mentioned also. Seven reports indicated that the fishermen were suffering no loss on scarred fish sent to market. One reported that most of the scarred fish were being disposed of, and that badly scarred fish sold for half-price. One report did not discuss marketability. The Saginaw Bay fishery in Lake Huron is not affected by the sea lamprey, according to reports from three conservation officers. Less than 1 percent of yellow pikeperch, suckers, and carp taken were reported scarred. In Lakes Erie and St. Clair, five reports indicated that 1 to 80 percent of the fish were scarred, with an average of 20 percent. Whitefish and carp were the species mentioned. No loss in marketability because of scars was reported.

The conservation officers' reports, based on interviews with an unstated number of commercial fishermen can be summarized as follows: 68 spawning streams were reported; approximately 30 percent of the commercial species were reported to be scarred or wounded from lamprey attack; lake trout appeared to be most heavily parasitized by the sea lamprey followed by the whitefish, sucker, yellow pikeperch, yellow perch, and carp; in some 52 percent (31 of 59) of the interviews commercial fishermen stated that no loss in sales value resulted from lamprey scars; 22 percent of the reports did not mention the subject, so it is not unreasonable to assume that there was no loss or only slight loss to the fishermen who were interviewed; and 26 percent of the reports outlined losses varying from 5 to 75 percent in value of the lamprey-scarred fish.

The financial losses are largest to fishermen operating out of ports north of Saginaw Bay in Lake Huron, and north of Muskegon in Lake Michigan. Almost no loss was reported for other regions. The amount lost depends on the severity of the wound. If it is completely healed, the fish can be marketed as easily as unscarred specimens. The actual financial loss also varies with the mode of selling. If fish are dressed or filleted, almost all the value can be obtained, but it is said that when they are sold in the round, a heavy loss is taken by the shipper. Some operators sell the lamprey-scarred fish, if badly wounded, for the smoked-fish trade. Before the loss to the commercial fishery can be ascertained accurately, numerous records must be taken at all seasons and localities to determine the percentage of scarred fish in the catches, and to check prices obtained for both scarred and unscarred fish.

PRESENT STATUS AND FUTURE OF THE SEA LAMPREY PROBLEM

Analysis of the literature and the limited amount of research done in Michigan, permit certain generalizations concerning the spread, the control, and the damage from the sea lamprey. After penetrating Lake Erie in the period 1921–28, the sea lamprey invaded Lakes Huron and Michigan and within the next 10 years became established. From a handful of known spawning localities in 1932 in Lake Erie, the reported spawning streams have increased to a total of 68 Michigan waters alone in 1946.

Reports of commercial fishermen indicate that about one-third of all commercial species in Michigan's Great Lakes waters may be marked with scars of varying degrees of severity but that the lake trout is the species most severly afflicted. Despite the rather high incidence of lamprey-marked fish taken in commercial gear, fishermen report that only in northern Lake Huron and northern Lake Michigan is there at present an appreciable loss to the industry from lamprey wounds. The exact extent of the loss cannot be determined without more accurate and detailed data on the number of scarred fish taken and prices received for them.

During the past 3 years the commercial fishermen most affected have demanded that either the state or the federal Government do something about the sea lamprey. House Joint Resolution 366 was introduced in the House of Representatives in the second session of the 79th Congress, instructing the U. S. Fish and Wildlife Service to "investigate and eradicate" the sea lamprey, and authorizing a sum not to exceed $20,000 yearly for a 10-year period. This joint resolution was passed by Congress and signed by the President.

Many individuals have proposed to eliminate the sea lampreys by trapping and destroying them on their spawning runs. One of the primary purposes of the work on the Ocqueoc River in Presque Isle County, Michigan, was to test this method of control which, in the light of the experiences there in 1945, would appear feasible if the necessary funds, materials, and labor were granted. The proper type of structure must be built on sheet-piling to prevent undercutting, and the traps and blocking arms must be constructed of screen not exceeding ½-inch mesh. It must be sufficiently wide and high to remain lamprey-tight under the worst flood conditions. Estimated construction cost for a weir of this type on the Ocqueoc River, where an opening 80 feet long by 5 feet high must be screened, is $5,000. Additional funds would be needed for maintenance and for attendants to keep the traps and screens under 24-hour observation during the peak of the run. Since 68 known lamprey spawning streams have been observed in Michigan alone, annual costs for construction, maintenance and operation of weirs would be very high and might be largely wasted unless similar programs were prosecuted vigorously by other states and provinces bordering the Great Lakes. Even if the attempt were made to block all spawning streams tributary to the Great Lakes, complete eradication of the lamprey would be difficult if not impossible. The possibility should not be overlooked, however, that annual operation of weirs on the more important spawning streams might at least keep the pest under control.

Complete knowledge of the life history and requirements of the lamprey is necessary for effective control. Some unsuspected weak link in the life cycle which offers means for control or eradication may be uncovered by further investigation. The possible commercial use of the sea lamprey should also be explored. Gage (1928) and Kerr (1926) indicated that in earlier days, both in the British Isles and in New England, the sea lamprey was regarded as a table delicacy. Gage (1928) mentioned also that the ammocoetes were a lucrative source of income to bait dealers in New York State at one time. Collection of young and adult sea lampreys for biological study in high school and college zoology courses is not unremunerative although the market is limited. It is possible that commercial utilization may be a more effective control than attempted eradication with engineering structures.

ACKNOWLEDGEMENTS

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LOCALIZED WEED CONTROL IN MANAGEMENT OF GAME FISH

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Abstract

The use of chlorinated hydrocarbons, namely trichlorbenzene, ortho-dichlorbenzene, and mono-chlorbenzene is indicated for the control of aquatic vegetation in localized areas. Ortho-dichlorbenzene is best because it settles fast and does not impart any great amount of odor or taste to the water. These chemicals, which are relatively insoluble in and heavier than water, sink to the bottom and sterilize it for a period of time. Trichlorbenzene is least satisfactory as it disperses far past the limits of the area to which applied. It also imparts a disagreeable odor and taste to the water and fish. It is possible that trichlorbenzene, with an emulsifier added, might prove an effective fish poison.

Chlorophyll is destroyed by these chemicals. The ground then becomes completely barren and, since the chemical is absorbed into the roots, it remains free of weeds from a few months to 2 or 3 years.

The chemical is applied under water with a high-pressure spray to spread it at rates of from 20 to 40 gallons per acre, depending on the species of weed to be killed. Great care must be used in hatchery applications. Water should be replaced in the pond before fish are restocked. Discharge or seepage from a pond being treated should not go to other ponds containing fish.

Carbon bisulfide, carbon tetrachloride, and trichlorethylene have also been found to be variously effective herbicides when used in the same manner.

Removal of small areas of weeds from completely weeded fishing waters permits the resumption of fishing and helps the population balance by creating openings where black bass can feed on small fish emerging from weed banks.

It might seem a trifle superfluous to attempt to tell men engaged in fishery work of the problems that can be caused by overabundant growths of aquatic weeds in fishing waters and in hatcheries. There are few in fisheries who have not at some time experienced serious difficulties arising from weed problems.

In the hatchery, weeds can cause screens to clog, fish to be stranded when ponds are drawn down, and seining to become difficult. Rotting weeds on the bottom can cause oxygen depletion and the formation of hydrogen sulfide or ammonia compounds which can directly cause mortality.

In fishing waters the difficulties arising from weeds are multiplied. The fact that the weeds produce foods through their decay is the only good blown by their ill wind. Heavily weeded waters are difficult to fish, which fact in itself often may cause overpopulated conditions. During the winter they often intensify conditions of winter kill under ice through depletion of oxygen. In waters of low salt content such as are found in some of our high mountain lakes and streams where the water supply is mainly runoff from precipitation, we find that weeds bring on an alkaline condition through removal of carbon dioxide and the consequent breakdown of bicarbonate into alkaline carbontes. In Arizona, in the neighborhood of 15,000 catchable trout were lost in 1945 from alkaline conditions in lakes and streams. Many otherwise suitable trout lakes cannot be stocked because of alkalinity caused by weeds which raise the pH to above 10.2 in some lakes. In the winter the situation is reversed and the weeds through their decay and the production of carbon dioxide can cause acid conditions sometimes fatal to trout.

Weeds play a big part in hampering the management of warm-water game fish such as largemouth black bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and black crappie (*Pomoxis nigro-maculatus*). Fishermen cannot keep the populations in check when they are unable to fish in heavily weeded waters. Too good protection is afforded the small forage fishes, such as the young of bluegill and black crappie, and the black bass consequently do not grow as fast as they should while the pan fish become dominant to the extent that growth is markedly reduced in all species.

Although the problem of controlling aquatic weeds is as old as fish management and is not diminishing as years go on, we find few workable solutions. Manual methods are expensive and laborious. These methods include dragging with chains and cables, raking or hoeing, and dredging. Nor are they too effective. In warm water, weeds often return within 3 weeks after being removed manually. Drying a lake or pond is normally effective in keeping the weeds out for a month or less after refilling.

Among chemical controls, copper sulphate is the old standby but is nevertheless a substance that most fishery workers dislike. Although it is effective on algae and to a lesser degree on weeds for a short period of time, the disadvantages of copper sulphate are so many that it has of late fallen into considerable disfavor and is now little used. Copper sulphate destroys many fish; the margin between the amount needed to kill weeds and the amount that is fatal to fish is so small that the chances of killing weeds without removing the fish at the same time are hardly better than 50:50. When copper sulphate is used in the hatchery the fish do not feed properly, and every application for weeds or disease retards the growth for a week or more. Plankton in the fishing waters suffers hugely from copper-sulphate treatments and, as the entire water must be treated, food conditions are made unsatisfactory by its use. Also to be taken into consideration is the fact that in waters of a pH higher than 7.5, copper sulphate is precipitated and rendered ineffective unless large quantities are used.

Another chemical often used for weed control is sodium arsenite. Some advantages of this compound are that it can be used locally and that it does not kill fish. Its disadvantages are that its effect is of brief duration and that it is deadly to mammals drinking the water. In one state in which sodium arsenite was used in a hatchery, cows drinking the water from the hatchery discharge were killed. The danger to live stock practically rules out the use of arsenite in most western waters.

The most successful weed control to date in Arizona has been achieved by the use of chlorinated hydrocarbons, namely, monochlorbenzene, ortho-dichlorbenzene, and trichlorbenzene. These compounds are characterized by high specific gravities and relatively low solubility in water. Ortho-dichlorbenzine, the one found best, has a specific gravity of about 1.4. Thus the effect is purely local as the heavy, relatively insoluble chemical sinks to the bottom, sterilizing the soil for a period of time. Although ortho-dichlorbenzene is very deadly to fish, normally only those are killed which come in contact with it when it is being applied. Greatest loss is to be expected in the treatment of heavy weed banks inhabited by fish.

Trichlorbenzene seems to be the most dangerous to fish, as it apparently diffuses readily throughout an entire pond, even though but half or less is treated. Only those weeds in the area of application are destroyed, but fish throughout the pond may be killed. The effect lasts from a few to several days.

Recently in a small Arizona lake, half of the surface acreage was treated with trichlorbenzene and all of the fish died. This chemical would not have been used if this result had not been partially anticipated, as it was desired to eliminate the resident black bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) and restock with trout alone. A week later the lake was treated with rotenone to determine if there were any survivors, but apparently the herbicide had killed every fish. The concentration of trichlorbenzene was approximately 5 p.p.m. It is possible that a lighter concentration might have eliminated all of the fish, particularly had an emulsifying agent been used with the chemical to obtain greater dispersal and more gradual settling to the bottom. An emulsifying agent can be prepared by combining one part potassium iodide with three parts "Triple-X Dresinate" and adding this mixture to 15 parts trichlorbenzene.

A later consequence of the treatment of this lake developed. The kill of the weeds was so good that the ground appeared completely bare within a month. A lethal alkaline condition previously present was eliminated and for the first time a large number of rainbow trout (*Salmo gairdnerii*) was planted successfully and was ready on the opening day of the season. However the first trout cooked were found to have a strong taste of the chemical in the flesh and this condition continued throughout the season. There is no inlet or outlet to this lake, its only source of supply being the runoff from precipitation. It was found that the taste in the water could be eliminated by the application of 5 p.p.m. of activated carbon, but it was decided to dispense with this treatment and to see how long it would take for the taste to dissipate naturally. It is interesting to note that this feature of taste in water and fish has not as yet been noted in a number of treatments with ortho-dichlorbenzene.

Ortho-dichlorbenzene seems to be the safest and most effective chemical of the group. With it, as much as 40 percent of a pond area has been treated without changing flavor of the water and without any mortality except those fish trapped in the weeds to which the chemical was applied. Ortho-dichlorbenzene settles to the bottom rapidly and fish are often seen swimming in and around the treated areas 10 minutes after treatment without ill effects. None of the chlorinated hydrocarbons offers any problem in regard to mammals. Horses, cattle, and dogs have been seen drinking the water immediately after treatment without effect. Force-feeding experiments with large dosages on sheep and cattle have shown that it takes considerable quantities even to affect an animal at all.

Ortho-dichlorbenzene is applied under high pressure through a manifold of nozzles under the surface of the water. This manifold is made of ¼-inch pipe, with individual pipes leading to the nozzles about 2 feet long and spaced about 20 inches apart. Pressure is obtained from a small gear pump of the type used for oil burners and power is supplied by a gas engine of about 1 horsepower. The Viking Pump Company makes a small gear pump with built-in pressure regulator that is ideally suited for the work. The best pressure for good dispersal is from 60 to 80 pounds. It is important that the nozzles be kept under water at all times during application. When the chemical is sprayed on the surface it does not break the surface tension until it comes together in a large mass, which then drops to the bottom, doing little good.

In the treatment of areas of any size the manifold is fastened to the stern of a rowboat and the craft is moved along at a speed calculated to spread the chemical at a rate of from 20 to 40 gallons per acre, depending on the resistance of the weeds in question. *Myriophyllum* is easily killed by a concentration of 20 gallons per acre, whereas *Potamogeton pectinatus,* one of the most resistant species, requires almost 40 gallons. Greater quantities of chemical per acre lengthen the duration of effect. Other factors enter into consideration. The action on weeds is more rapid at higher temperatures, although it is probably just as sure in colder water but takes a longer time for effect. The time of the year is important also. The best period seems to be in the spring when the weeds are green and about a foot off the bottom. Good distribution is important, both from economic considerations and from the standpoint of results. The boat should be moved back and forth working out from shore in lanes, so that each lane barely overlaps the previous one. The man at the oars should be an experienced boatman.

Ortho-dichlorbenzene kills the plants by destroying the chlorophyll. Furthermore, some of the compound is absorbed down into the roots with the result that the ground itself is sterilized for a period of time, varying with the temperature, character of the bottom, and type and amount of weeds in the water. Within a few hours or less, the weeds usually turn white and within from 1 to 4 weeks they drop to the bottom and disintegrate, after which the bottom surface appears completely bare. Duration of effect is from a few months to 2 or more years, according to local conditions and the thoroughness of treatment. If a whole pond is treated, the effect may last for years.

Great care must be exercised when ortho-dichlorbenzene is used in the hatchery, especially if there are fish in the pond to be treated. If fish are present it is not considered wise, on the basis of present knowledge, to treat more than 1 percent of the bottom area at a time. For treatment of hatchery ponds it is usually most expedient to use a small weed-burner pressure tank with a nozzle taking the place of the burner head. If fish can be removed, the whole pond may be treated. It is not wise to treat hatchery ponds while the discharge or seepage goes to other fish.

For best results we use a flat disc nozzle with a 0.031 aperture which throws a flat, fan-shaped spray horizontally. The Spray Engineering Company of Somerville, Massachusetts makes a spray nozzle that suits the purpose very well. Cost of chemicals is variable but in general runs from 9 to 12 cents per pound, or from $1.00 to $1.40 per gallon; at this rate, the cost per acre runs from $25 to $50. It might be mentioned that it is also possible to use carbon bisulfide in the same way for the same purpose. Its properties are only slightly different. Drawbacks of carbon bisulfide are its offensive odor, its slight solubility, and the fact that it is probably only about 75 percent as effective as ortho-dichlorbenzene or trichlorbenzene. In its favor are the facts that it is less lethal to fish, the odor disappears from the surface of the water shortly after application, and it is much cheaper. Carbon tetrachloride is about 50 percent as effective as the chlorinated hydrocarbons and trichlorethylene seems to be about the same. Not too much work has been attempted with these latter two compounds.

We seldom try to remove all of the weeds in any lake or pond as it is felt that a certain quantity of them is necessary for the food supply, and for outside hatcheries we do not consider it wise from the standpoint of fish safety to treat more than one fifth of a body of water at any given time. If an entire lake must be treated and the fish saved, it is best to treat a fifth at a time, waiting a few weeks between treatments.

By removing weeds from small areas of a lake, usually from a half acre to an acre for each treated spot, it is possible to open waters to fishing that would not ordinarily be fishable. There is one 200-acre lake in Arizona on which fishing was ordinarily concluded each year by the first of June, when the surface became almost completely closed in with semi-emergent *Myriophyllum.* Early in 1945, small areas in desirable fishing spots totalling some 6 acres were cleared of weeds with trichlorbenzene and ortho-dichlorbenzene. This treatment permitted year-around fishing. Although the lake is very warm (the temperature reached 95°F. at times in the summer), some of these treated areas now have been clear of weeds for a year. When such areas are cleared, edges are created where the black bass can lurk and catch the young fish coming out of the weed banks. This makes for bigger bass, better population balance, and better bass fishing in these spots.

The method as outlined needs improvement and experimentation to work out its most efficient and safest procedure. Although by no means perfect, it is possibly the best method for controlling aquatic weeds in limited areas so far in use.

THE CONTROL OF AQUATIC PLANTS WITH FERTILIZERS IN REARING PONDS AT THE LONOKE HATCHERY, ARKANSAS

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Abstract

Many species of aquatic plants can be prevented from growing in fish rearing ponds by the application of commercial fertilizers in the right amounts. The total cost of controlling plants and producing a crop of fish with fertilizers lessens the expenditure for labor in the fall draining period and justifies the use of additional fertilizer.

Turbidities should be minimal to get the maximum results from the fertilizer. Plants that cannot be held in check with fertilizers should be killed by drying out the pond bottom. Newly discovered weed killers should be tried out on emergent water plants.

Fertilizers should be applied early in the growing season and in quantities that will stop the growth of plants before mid-June. Killing plant growths after that time entails the risk of lowering the free oxygen in the water, consequently endangering the fish. Every pond should be regarded as an individual problem and should be fertilized in accordance with the exact amount needed to produce desired results.

Introduction

The conventional manner of operating warm-water fish rearing ponds is to start the new year with a dry pond. In the early spring, well in advance of the spawning time, the pond is flooded, fertilized and made ready for the coming growing season. It is stocked with fish in the early spring and throughout the summer only sufficient water to maintain the desired water level is allowed to flow in. The pond is fertilized at regular intervals and in the fall it is drained and the fingerlings produced are distributed. The ponds are allowed to remain dry until the following spring.

When drained most ponds must be raked to prevent the loss of fish in aquatic vegetation that has grown during the summer. The density of plants ranges from only a light stand to as high as 20 tons per acre in certain ponds. The raking and removal of vegetation is expensive, and this paper is concerned with the use of sufficient fertilizer to control plants, thus saving on operating costs and at the same time increasing the size and number of fingerling fish reared.

Discussion

The role of aquatic plants has been a controversial subject in connection with fish production in the readjustment of natural waters and impoundments. The thought must be borne in mind that this article is concerned with the operation of fish rearing ponds in the production of warm-water game fish and forage minnows. Species of fish that are dependent upon leafy aquatic vegetation for food are not considered. The bottom soils and fertility of a pond are the basic links in a food chain involving plankton, forage fish, and game fish. Plants form a harbor or protection for small fish in open waters but the idea in fish-pond management is to produce food in sufficient quantities for both the plankton and fish so that the food cycle can be followed through. Since plankton and forage minnows are both taken as food by young fish, the object is to produce a bountiful supply for the game fish and thus eliminate the need for vegetation as a protection against cannibalism.

Aquatic plants have become so dense in some of our ponds that the game fish have been suffocated. In some ponds the plants have grown so heavy that the adult bass could not feed on forage minnows, and the forage fish were not utilized. We have had one pond in which emergent lilies, *Nelumbo lutea,* lowered the food production and retarded the growth rate of select largemouth black bass to the extent that the fish weighed less after passing a summer in the pond than when stocked in the early spring.

This experience with light and heavy growths of aquatic plants and fish production has been compared with complete lack of aquatic plants in ponds that are heavily fertilized. Heavily fertilized ponds will produce from two to three times as many fish per season as unfertilized ponds which have an average crop of submerged and emergent aquatic plants (Hogan, 1933). The fertilization of ponds costs from $10 to $15 per surface acre, depending upon the amount needed to produce the desired plankton bloom. We have tried to use enough fertilizer to create a plankton bloom that will reduce visibility to a depth of 18 inches (Smith and Swingle, 1942), or even less. Rich bottom soils respond more quickly in some ponds than in others and such natural factors must be taken into consideration in setting up a tentative fertilizing schedule. Pond run-off or excessive seepage decreases the effect of the fertilizer and reduces fish production. The amount of fertilizer needed to hold plants in check and to produce a maximum crop of fish depends upon: (1) the natural fertility of the pond; (2) the amount of seepage and run-off; (3) the strength and kinds of fertilizer used; and (4) the species of aquatic plants in the pond.

There are some submerged and many emergent plants (Hogan, 1934) that cannot be eliminated from ponds by the use of fertilizers. Therefore, the prevention of plant growths calls for thorough drying of the pond bottoms to kill these hardy varieties and with lotus it is necessary to oil the leaves because winter drying of the pond bottom does not retard summer growth. Factors that create turbidity in infertile ponds, such as soils in suspension resulting from crayfish activity and levee wash, are more likely to retard than to aid fish production and the turbidity will control plants as effectively as clouds of plankton. The eradication of

TABLE 1.—*Effects of fertilization on aquatic vegetation in 1945 in 42 experimental ponds at the Lonoke Hatchery*

Pond		Pounds and type of fertilizer			Aquatic vegetation		
Number	Area (acres)	6–8–4	16 percent nitrate soda	Total per acre	Killed	Partially killed	Not killed
1	0.85	400	10	517	...	...	X
2	0.85	500	10	600	X	...	...
3	0.85	500	10	600	X	...	...
4	0.85	500	10	600	X	...	...
5	0.85	500	10	600	X	...	...
6	0.85	500	10	600	X	...	...
7	0.85	500	10	600	X	...	...
8	0.45	500	10	1,113	X	...	...
9	0.85	1,000	40	1,123	...	...	X[2]
10	0.85	800	20	964	...	...	X[1]
11	0.85	700	10	835	...	...	X[1]
12	0.85	700	10	835	...	...	X[1]
13	0.85	600	...	705	...	...	X[1]
14	0.85	700	10	835	...	...	X[1]
15	0.85	800	40	988	...	...	X
16	0.85	500	10	600	X	...	...
18	0.85	600	...	705	...	...	X[1]
19	0.85	600	20	729	X	...	...
20	0.85	600	20	729	X	...	...
21	0.85	600	20	729	X	...	...
23	0.85	600	20	729	X	...	...
24	0.85	200	20	258	X	...	...
25	1.85	600	20	335	...	X	...
27	1.85	1,250	45	700	...	...	X
28	1.85	800	...	432	X	...	...
29	1.85	1,700	90	968	...	X	...
30	1.85	800	...	432	X	...	...
31	1.85	900	50	513	X	...	...
32	2.85	1,850	145	700	X	...	...
33	4.5	1,500	50	344	X	...	...
34	4.5	1,500	150	366	...	...	X
35	4.5	2,100	25	472	X	...	...
36	4.5	2,750	90	631	...	...	X
38	7.0	4,000	280	611	...	X	...
39	7.0	4,800	360	737	X	...	...
40	5.0	2,100	130	446	X	...	...
41	5.0	800	...	160	...	...	X
57	10.0	2,700	150	285	X	...	...
58	6.0	2,000	150	358	...	...	X
59	6.0	1,800	100	316	X	...	...
60	6.0	500	40	90	...	X	...
61	6.0	500	50	91	...	X	...

[1] Ponds drained and refilled in June
[2] Ponds drained in May and again in June

obnoxious water plants from fish ponds should take priority over fertilization work. These plants should be killed out at once. Delayed action means more trouble and expense later, for the plants spread rapidly in shallow or clear waters.

Financial justification for the use of fertilizers is seen if the advantages of plant control are considered. The ordinary hatchery operator may hesitate to spend $10 or $15 per acre to fertilize for fish production alone, but with the added feature of plant control the prorated cost is quite different. In the average fish pond the cost of controlling plants by raking equals the purchase price of the fertilizer.

During the last several years we have been trying to develop a method of pond fertilization whereby the time of application and the amount of fertilizer used would result in control of aquatic plants and there would be need for little additional labor in the fall draining season. This plan has been followed and the annual fish production has improved both in quality and quantity. Forty-two ponds were fertilized during the 1945 season; the effects on plant life are shown in Table 1.

POND HISTORY AND DETAILS OF FERTILIZATION

At the close of the summer season 23 ponds were without aquatic plants, a partial kill was affected in 5 ponds, and 14 ponds had normal to heavy stands of both submerged and emergent aquatic plants. All of the ponds have been fertilized for several years and a considerable amount of the fertilizing elements has persisted in the pond bottoms. This residual fertilizer has presumably affected the results obtained in different ponds.

Fertilizer (costing $35 per ton) was applied first in the middle of March and was added until about September 1. The number of applications per pond varied from two to six; the first two were spaced about a month apart and were followed by further treatment when increasing water transparency indicated that more was needed. The amount of fertilizer placed in the ponds ranged from 235 to 100 pounds, per acre, for the first application, but as the waters became warmer the amount was decreased to about 50 pounds per acre. The vegetation killed was all fine-leaved submerged plants and arrowhead that was in the deeper sections of the ponds.

A brief explanation will be given concerning the ponds that continued to produce plants although most were heavily fertilized. Pond No. 1 had been used for years to winter broodfish and as a spawning and rearing pond in the summer. Thus it had not been dried out for the past 15 years and the plants could not be held in check with the amount of fertilizer used. Pond No. 8 was stocked with black crappie and although the pond is much smaller than those adjoining, it received the same total amount of fertilizer. The resulting over-fertilization caused the loss of a few small crappie at one time in the summer. The plants (arrowhead) were killed early in the summer. Pond No. 9, along with others that were drained and refilled in June, exemplifies what can be expected in farm ponds having a change of water in the summer by seepage or surface run-off after heavy rains. The plants in these ponds appeared to be breaking down but when the ponds were drained, refilled, and fertilized, new plants came along in the pond bottoms and made a heavy growth by fall. Pond No. 18, in particular, was fertilized in the spring and after draining in June produced a very heavy crop of plants by fall. The plants became so dense that manual removal was necessary to save the adult stock from suffocation. This pond would also benefit by a drying-out period of several months.

Pond No. 15 was flooded in February and stocked with bullheads for operation through the summer. During the spring and summer months, 840 pounds of commercial fertilizer and 1,000 pounds of stable manure were placed in the pond. In former years this pond had a heavy growth of coontail, *Ceratophyllum,* and lotus, *Nelumbo.* During the summer the lilies were sprayed with kerosene and used motor oil and as soon as the pond surface was cleared of shade a growth of filamentous algae, *Hydrodictyon,* formed. This heavy algal mass was removed with a solution of 0.25 p.p.m. of copper sulphate in April, and afterwards we were unable to get a plankton bloom established. At no time during the summer were there indications that our fertilizing efforts had created unfavorable conditions for the submerged plants.

Pond No. 23 had a small area populated with cattails, *Typha,* and bulrushes, *Scirpus.* All plants in deeper water were killed but those along the shoreline had to be cut with a scythe. Pond No. 25 was heavily vegetated with fine-leafed water weeds, *Potamogeton;* however, at the close of the summer the plants were nearly all dead. Clumps of dead plant material were floating around in the pond, and the total amount of fertilizer was limited because of this fact. Pond No. 27 which has been operated continuously for several years was heavily vegetated with submerged plants. After the pond was fertilized the plants appeared to be breaking down but at the close of the summer a heavy growth was again present.

Pond No. 29 was flooded and fertilized in March, and by July 1, a total of 1,020 pounds of fertilizer had been placed in it without creating a phytoplankton bloom. Filamentous algae started growing and in a short time the pond surface was entirely covered. The pond was treated with a 0.25 p.p.m. solution of copper sulphate on July 31, and again on August 2. Only a part of the heavy algal mat was killed by the two applications and we hesitated to treat the pond again for fear of losing fish. Judging from the experience of other investigators (Surber, 1945) the light applications of copper sulphate should have been continued until the mat was killed.

In Ponds No. 34 and 41 which were both heavily vegetated with broad-leafed *Potamogeton* the amount of fertilizer used did no damage to the plants. Both ponds are poor producers of fish, yielding about 10 percent of a normal crop, and will continue in that category until steps are taken to destroy the plants that shade out the pond. Ponds No. 36 and 38 had dense growths of lotus, and scattered growths of submerged plants over 80 percent of their area. Shading of the ponds by emergent plants prevented the formation of a plankton bloom although part of the lilies were killed near the end of the summer by spraying with kerosene and used motor oil. Both ponds are poor fish producers and more attention must be given the control of emergent plants before fertilization will have the desired results. Ponds No. 60 and 61 were stocked with forage minnows and carp. The feeding activities of the carp along with the limited amount of fertilizer was sufficient to hold the aquatic plants in check and prevent normal vegetative growth. Fish production would undoubtedly have been improved in these ponds if more fertilizer had been used.

The rooted, fine-leafed, submerged plants were quite easily killed, or their growth retarded, by a plankton bloom. The coontail and emergent lilies and cattail plants were unaffected by fertilizer although a considerable amount was used in an effort to bring about a kill. Many of the ponds that have been fertilized for years seem gradually to accumulate large amounts of unused elements that remain inactive in the pond bottoms through the summer. Better fish production could be expected if this reserve of fertility were brought up into the water.

Conclusions

1. The use of commercial fertilizers to control the growth of submerged aquatic plants in fish ponds is practical. The expense of additional fertilizer is offset by decreased labor in the fall draining period.

2. Emergent water plants may be controlled either by drying out the pond bottoms in the fall months, or by cutting and oiling the leaves during the summer. The use of recently discovered weed killers might be the answer to the problem.

3. The best results can be obtained by starting to fertilize early (in February or March in Arkansas). The first application of fertilizer should be at the rate of 100 to 200 pounds per acre to establish a plankton bloom before higher aquatic plants begin growing in the spring.

4. Certain species of plants survive under heavy fertilization. With them the drying of the pond bottom in winter is recommended as a control measure. Ponds that are flooded overwinter can be fertilized to establish the phytoplankton bloom as early as possible in the spring.

5. Turbidity, resulting from the activities of carp and crayfish or from clay silt washed into the pond, retards plant growth but lowers fish production.

6. Heavy blankets of filamentous algae must either be removed by hand or killed with copper sulphate before a phytoplankton bloom can develop.

7. The annual program results in the deposition of unused fertilizer in pond bottoms. Some method of recovering these fertile organic bottom deposits in filled ponds should be devised so as to utilize the nutrient elements more fully.

8. So many factors are involved in the fertilization of fish rearing ponds to control aquatic vegetation that each pond must be treated as an individual problem throughout the entire growing period.

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RATES OF SURVIVAL AND GROWTH OF BLUEGILL YOLK FRY STOCKED AT DIFFERENT INTENSITIES IN HATCHERY PONDS[1]

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ABSTRACT

Data gathered during two summers from five ponds at the Wolf Lake Hatchery near Kalamazoo, Michigan, showed little correlation between the rate of survival and the intensity of stocking bluegill yolk fry. Ponds stocked at rates that ranged from 2,500 to 323,000 yolk fry per acre were drained at the end of the first summer, the first winter, and the second summer. Not more than 40 percent of the fry stocked in the spring survived the first summer in any pond. By the end of the second summer as few as 1 percent and not more than 20 percent of the original stock remained. Fish that were stocked at lesser intensities grew faster than those stocked more heavily. Competition from Iowa darters apparently seriously impaired the survival of bluegill yolk fry in one pond during the first summer. In another pond green sunfish, that entered as young of the year through the water supply during the first summer, became dominant over the bluegills in number and total weight by the end of the second summer. Under the most favorable conditions for growth (little competition and ample food) bluegill yolk fry grew so rapidly that they spawned when 12 months old and reached an average total length of 6 inches in 17 months.

INTRODUCTION

For many years it has been the practice in hatcheries where sunfishes are raised to stock the ponds early in the season with either "breeder" adults or with yolk fry, and, after feeding and caring for the young fish for 4 or 5 months, to distribute them to various waters. Realizing that oftentimes it may be difficult to hold the adults over winter or to secure them in the spring, Lydell (1921) devised a method of collecting bluegill (*Lepomis macrochirus*) yolk fry from natural waters, transferring them to hatchery ponds, and rearing them to fingerling size. Thus the handling of the adult fish was eliminated. This method of rearing bluegills has since become traditional, at least in Michigan, and is still practiced in many parts of the country.

Even though tremendous numbers of bluegills have been reared in hatcheries, there is little information available on the survival of yolk fry to any subsequent stage of development. When fish spawn under natural conditions, the rate of survival of the eggs that are fertilized to the yolk fry stage, to the end of the first summer, to the second, . . .

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[1] Contribution No. 386 from the Department of Zoology, Indiana University.

is not definitely known. The eggs of nest builders, like the sunfishes, are likely to have better chances of survival than those of fishes such as the yellow perch or carp that broadcast their eggs and provide little or no protection during the hatching period. Even with such care as is furnished by the male bluegill, the rate of survival to any stage beyond the fertilized egg is unknown but is believed to be very low. Hazzard (1945) stated that at the end of 4 years only 3 bluegills, 5 pumpkinseed sunfish, 30 rock bass, and 13 largemouth bass of each 100,000 fry estimated to have been produced in the first year of the study had survived. One of the primary reasons for the existence of fish hatcheries for warm-water fishes was to reduce that "tremendous natural waste" to a minimum and to assure a higher survival rate.

MATERIAL AND METHODS

In 1941, five ponds, that ranged in size from 0.86 to 1.60 acres at the Wolf Lake Hatchery of the Michigan Department of Conservation near Kalamazoo, were made available for experiments on the rates of survival and growth of bluegill yolk fry.[2] The ponds had lain dry during the winter of 1940–41 and were filled with water during April 1941. The maximum depth of each pond was 7–8 feet. Ponds 1 and 2 (actually Ponds 8 and 7 respectively renumbered for this study) had soft mud bottoms with sand shores, Pond 3 had a bottom of sand mixed with mud, and the bottoms of Ponds 4 and 5 were sand. Cattails grew along the shores of Ponds 1, 2, and 3; Ponds 2, 3, and 5 supported fairly heavy growths of *Chara*. Each pond was individually supplied with water either directly from a spring or through a bubbler system from another pond and each could be drained separately.

The procedure of stocking hatchery ponds with bluegill yolk fry, as practiced at the state fish hatcheries in Michigan (Lydell, 1921) was followed. Yolk fry, collected from Lime Lake, Van Buren County, Michigan, were transferred to the hatchery in cans, placed on cheesecloth trays at depths of about 18 inches from the surface, and covered with coarse-meshed screens. After the fry had risen from the trays, the trays were removed from the ponds.

The numbers of fry stocked in the ponds were estimated in the following manner. Fry were drawn into a glass tube, with an inside diameter of one-half inch, by holding a thumb over the upper end of the tube, placing the lower end of the tube in the can containing the fry and releasing the thumb. As the water replaced the air in the tube, the fry were carried along with it. By replacing the thumb over the upper end of the tube, the fry were retained in the tube and the tube withdrawn. Then the lower end of the tube was covered with the other hand to prevent any loss of fry. The fry were allowed to settle to the lower end of the tube and the height of the column of fry was measured to the nearest one-eighth inch. On the basis of an estimated figure of 1,800 fry per inch of tube length, Ponds 3, 4, and 5 were stocked at intended rates of 100,000 fry per acre, 20,000 fry per acre, and 2,000 fry per acre respectively on May 27 (Table 1). On May 31, Ponds 1 and 2 were stocked by personnel at the Wolf Lake Hatchery at an intended rate of 200,000 fry per acre, using an estimate of 1,500 fry per inch of tube length (Table 1).

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[2] I am grateful to Dr. A. S. Hazzard, Director of the Institute for Fisheries Research of the Michigan Department of Conservation for permission to publish these data. Thanks are due members of the Institute Staff, Mr. Jay Marks, Superintendent, and other personnel at the Wolf Lake Hatchery, who assisted in this study.

TABLE 1.—*Surface area (acres) of five ponds at the Wolf Lake Hatchery, near Kalamazoo, Michigan, together with the intended rates of stocking, the numbers of fry actually stocked and the percentage error between the two*

Pond	Surface area (acres)	Planned stocking	Actual number stocked	Actual number per acre	Percentage error
1	0.90	180,000	291,000	323,333	61.7
2	1.60	320,000	514,100	323,333	60.7
3	0.86	86,000	100,686	118,454	17.1
4	1.01	20,200	23,874	23,638	18.2
5	1.27	2,540	3,114	2,452	22.6

In order to determine the accuracy of the estimated numbers of fry placed in the ponds, two 1-inch and two 2-inch samples of the fry stocked on May 27 were preserved and counted. Similarly, as a check against the fry stocked on May 31, three 1-inch and three 2-inch samples were preserved and counted. The numbers of fry in the samples preserved on May 27 ranged from 1,840 to 2,285 per inch of tube length with an average of 2,076 per inch rather than the estimated 1,800 (Table 2). That average count was 15.3 percent higher than the estimate. The numbers of fry preserved on May 31 ranged from 2,257 to 2,513 per inch with an overall average of 2,425 fry per inch (Table 2). Here the average was 61.7 percent higher than the estimated number of 1,500.

TABLE 2.—*Samples of fry preserved and counted as a check against the accuracy of the estimated figures of 1,800 and 1,500 fry per inch of tube length as used in stock-five ponds at the Wolf Lake Hatchery on May 27 and May 31, 1941*

Date	Size of sample (inches of tube)	Estimated number per inch	Actual number per inch	Percentage error
May 27	1	1,800	1,934	7.4
do.	1	1,800	2,285	26.9
do.	2	1,800	1,840	2.2
do.	2	1,800	2,279	26.6
May 31	1	1,500	2,496	66.4
do.	1	1,500	2,478	65.2
do.	1	1,500	2,257	50.5
do.	2	1,500	2,489	65.9
do.	2	1,500	2,296	53.1
do.	2	1,500	2,513	67.5

The considerable differences between the intended rates of stocking and the actual numbers of fry placed in the ponds are largely attributable to practical difficulties. Inasmuch as yolk fry are extremely fragile, it is not feasible to hold them in cans long enough to make counts of samples before stocking the ponds. Further, such handling of fry would, in all probability, kill them. The stage of development directly determines the number that can be contained in a space 1 inch long in the sampling tube. Differences in age are directly correlated with activity of the fry which, to a greater or lesser extent, is governed by the amount of yolk present. Newly hatched fry, having a large amount of yolk material present, are quite inactive, and are bright golden in color. As they grow older, the yolk is absorbed and the fry gradually become more active and the golden color becomes less pronounced. The fry placed in Ponds 1 and 2, although collected 4 days later, were more golden and were not nearly so active as those stocked in the other ponds. In addition, the fish put in Ponds 1 and 2 were of an average length of 5.0 millimeters whereas those planted in Ponds 3, 4, and 5 averaged 5.8 millimeters long. Because the fry used in stocking Ponds 1 and 2 were younger than those placed in the other ponds, they settled out in the measuring tube into a more compact mass.

The fish used in the present experiment were not fed at any time. However, Pond 1 was treated with 100 pounds of Swift and Company's Red Steer Brand (N-P-K) 10-6-4 commercial fertilizer and 50 pounds of crushed limestone once a month for 4 months (June through September) during each of the summers of 1941 and 1942.

During the week of October 24, 1941, the five ponds were drained and the total number and total weight of the fish in each was determined. Special effort was made to recover any fish that had become stranded during the drawdown. In Ponds 1 and 2, where there were large numbers of bluegills and few other fish present, the total numbers were determined by sampling. Ten samples of 1,000 bluegills each were weighed and the average weight per thousand established. Then, by dividing the total weight of the bluegill population by the average weight of the 10 samples, the number of bluegills in the pond was obtained. In Pond 3, where large numbers of green sunfish fry (*Lepomis cyanellus*) had entered through the water supply, 10 samples of 1,000 fish each were counted and weighed. Then the green sunfish were sorted from the bluegills in each sample and a ratio of abundance between the two species was established. From these data and the total weight of the population in Pond 3, the numbers and weights of each species were estimated. The green sunfish sorted from the 10 samples were destroyed but no attempt was made to sort the green sunfish from the remainder of the population. Individual length measurements were taken from random samples of bluegills from Ponds 1, 2, and 3. Individual length and weight measurements were made for all of the bluegills recovered from Ponds 4 and 5.

As soon as the fish had been removed from a pond, the pond was refilled with water and the fish, having been counted, measured, and weighed, were returned to the pond from which they had been taken. All fish other than bluegills and the green sunfish mentioned in connection with Pond 3, were destroyed. Following the draining of the ponds in October 1941, the water in each pond was kept at a level 1 foot lower than that maintained during the summer in an attempt to discourage muskrat tunneling in the levees.

On April 28–30, 1942, the ponds were drained again and the fish counted, measured, and weighed as in October 1941. Bluegills were returned to their respective ponds and other fish discarded. The water level in the ponds was restored to the same level as that maintained during the previous summer. At that time most of the green sunfish present in Pond 3 were destroyed.

Again, during the week of October 19, 1942, the five ponds were drained and the fish counted, measured, and weighed as on the two previous occasions. Unfortunately, the fish were not returned to their respective ponds but were distributed by the hatchery personnel and the experiment concluded.

When a pond is drained and the fish removed, it is inevitable that some of the fish will die or be killed during the operation. In the present study, these losses were usually light but in some cases factors beyond control such as sudden changes in weather or temperature caused losses that constituted a considerable portion of the population. In order that this mortality should not be misidentified as "natural" mortality, the numbers of fish killed in handling and those actually returned to the ponds were recorded each time the ponds were drained.

Survival of Bluegill Yolk Fry

The data on the survival of bluegills beyond the yolk-fry stage, as shown in the present study, indicate that the greatest "natural" mortality occurred during the first summer of life (Table 3, Fig. 1). In none of the five ponds under consideration did more than 39.3 percent of the yolk fry planted in May survive to the following October. During the ensuing winter, the rate of mortality was lower in each pond than during the first summer. Of the fish returned to the ponds in October 1941, at least 55 percent survived until April 1942. During the second summer of life the rate of survival depended to a great extent on what happened during the first summer and winter. Under "normal" conditions, as indicated by the data from Ponds 1, 2, and 5, a mortality of 30–40 percent during the second summer is apparently usual.

The highest survival (39.3 percent) during the first summer occurred in Pond 1 that had been stocked at an unusually high rate but had also been fertilized. There the fertilizer apparently brought about a sufficient increase in the food supply to permit a greater survival than in Pond 2 (18.0 percent) which had been stocked at the same rate but had not been treated with fertilizer. The apparent inability of Pond 2 to provide an

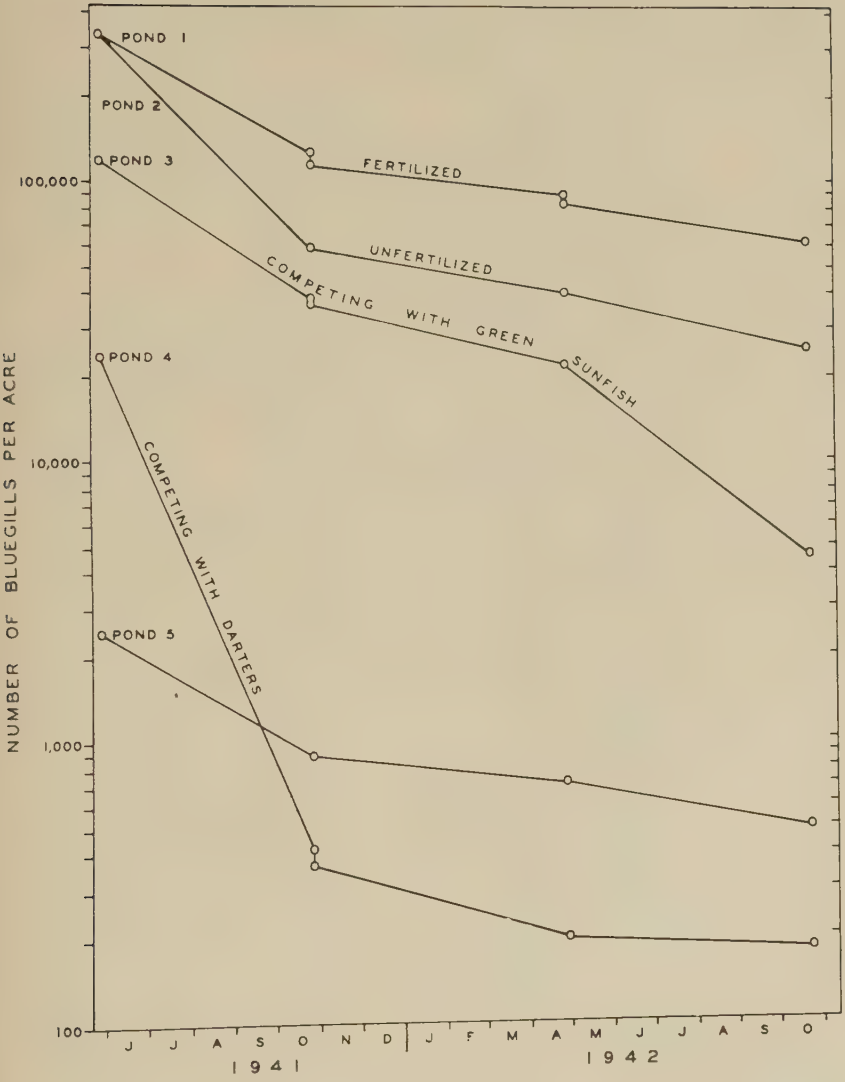

FIGURE 1.—Survival of bluegill yolk fry in five ponds at the Wolf Lake Hatchery, as indicated by the numbers of fry placed in each pond in May 1941 and the number recovered from each pond at the end of the first summer (October 1941), the first winter (April 1942), and the second summer (October 1942). The vertical sections of the curves show the numbers of fish lost in handling each time the ponds were drained.

TABLE 3.—*Rates of stocking bluegill yolk fry per acre in five ponds at the Wolf Lake Hatchery, during May 1941, together with the numbers of fish recovered and the numbers of fish returned to the ponds when the ponds were drained during October 1941, April 1942, and October 1942, and the rates of survival for each of the different periods*

Pond	Number planted per acre May 1941	Number per acre recovered, October 1941	Percentage survival, May 1941 –October 1941	Number per acre returned to pond, October 1941	Number per acre recovered, April 1942	Percentage survival, October 1941–April 1942
1	323,333	127,104	39.3	113,891	89,433	78.5
2	323,333	58,063	18.0	57,515	39,936	69.4
3	118,454	38,278	32.3	37,129	22,222	59.9
4	23,638	419	1.8	366	202	55.2
5	2,452	892	36.4	892	712	79.8

Pond	Percentage survival, May 1941 – April 1942	Number per acre returned to pond, April 1942	Number per acre recovered, October 1942	Percentage survival, April 1942 – October 1942	Percentage survival, October 1941 – October 1942	Percentage survival, May 1941 October 1942
1	27.7	83,649	60,500	72.3	52.7	18.7
2	12.4	39,838	25,171	63.2	43.8	7.8
3	18.8	22,024	4,594	20.9	12.4	3.9
4	0.9	200	181	90.5	49.5	0.8
5	29.0	712	487	68.4	54.6	19.9

adequate food supply for the large population of bluegills probably caused the greater mortality rate than that in Pond 1. The mortality over winter in Pond 2 (30.6 percent) was greater than that in Pond 1 (21.5 percent) and continued to be so during the second summer. At the end of 17 months (October 1942) only 7.8 percent of the original planting remained in Pond 2 whereas 18.7 percent of those fish originally placed in Pond 1 were still present.

In Pond 5, 36.4 percent of the original yolk fry survived to the end of the first 5 months. The loss over winter was less than in any of the other ponds (20.2 percent). Likewise, at the end of 17 months the 19.9 percent survival of the original planting was greater than that in any other pond.

In Ponds 3 and 4 the survival of the bluegill fry was apparently hampered by the presence of other kinds of fish. The poor survival during the first summer in Pond 4 (1.8 percent) was probably caused by the large population of Iowa darters (*Poecilichthys exilis*) that literally "took" the pond. Although the darters were removed in October 1941, the loss of bluegills the following winter was greater (44.8 percent) than in any other pond. The reason for that high over-winter mortality is not obvious. However, at the end of the second summer, 90.5 percent of the bluegills returned to the pond in April were still there. The high survival during the second summer in Pond 4 might well be attributed to the small size of the population.

During the first summer in Pond 3, the survival (32.3 percent) was very nearly that in Ponds 1 and 5. During the winter 40.1 percent of the bluegills failed to survive, and the following season only 20.9 percent of those placed in the pond in April 1942 were present late in October. This decrease is probably traceable to the presence of the green sunfish. When the pond was drained in April 1942, it was estimated that all but 409 of the green sunfish were removed and destroyed. Thus, at the beginning of the second summer, the total population of Pond 3 consisted of 409 green sunfish and 22,024 bluegills, all entering their second summer of life. During the summer of 1942 the green sunfish spawned but the bluegills did not. As a result, the population at the end of that summer was made up of an estimated 48,500 green sunfish and 4,594 bluegills. Thus, it is apparent that the green sunfish were gradually taking the pond over at the expense of the bluegills. Further evidence of this change is to be found in the total weights of each species. At the beginning of the second summer (April 1942) there were 148.5 pounds of bluegills and 19.1 pounds of green sunfish per acre of pond surface. By October 1942 the bluegills had increased to 171.5 pounds per acre and the green sunfish to 187.2 pounds per acre. In other words, the green sunfish population, which made up only 11.4 percent of the weight of the total population in April 1942, increased during the next six months to a point where they constituted over half (52.2 percent) of the total weight.

From the foregoing data it is apparent that the survival of bluegill yolk fry is subject to the influence of many factors. Of these, food supply, space, and competition with other species seem to have been of primary importance in this study. If the available food supply were the main controlling factor, there should have been a greater percentage survival in Pond 5. That pond was stocked with considerably fewer fish per acre than any of the others and yet the rate of survival was substantially the same as that in Ponds 1 and 3. Further, any predation by snakes, birds, turtles, etc., should have been greater in the other ponds where the populations were much denser. Then, too, if space and competition are to be considered as controlling factors in survival, conditions in Pond 5 were more favorable than in the other ponds.

Apparently there are factors beyond the scope of this study that regulate the survival of yolk fry to the fingerling stage and beyond. It was mentioned earlier that the greatest mortality occurred during the first summer of life. At what time during the summer the mortality took place is not known. It has long been surmised by hatchery workers that considerable "natural" mortality may occur before the yolk fry rise from the cheesecloth trays or shortly after they become free-swimming.

GROWTH

Other things being equal, the rate of growth of fishes in newly stocked waters is dependent on two factors: (1) the intensity of stocking, and (2) the rate of survival of the original planting. If the rate of survival were the same in all ponds, the growth of the fish would be inversely proportional to the intensity of the stocking, *i.e.*, the fish stocked at a lower rate would grow faster than those stocked at a higher rate. However, no matter what the rate of stocking of a pond may be, the rate of survival, inasmuch as it determines the density of the population, has a considerable effect on the rate of growth.

Rate of growth in fishes can be measured in two ways: (1) increase in length, and (2) increase in weight over a given period of time. Although length and weight in fishes are correlated to a certain extent, two fish of the same species and of the same length need not necessarily have the same weight. Conversely, two fish of the same weight are not necessarily the same length.

At the end of the first summer the average total length of bluegills in the five experimental ponds ranged from 1.0 (Pond 1) to 3.9 inches (Pond 5) as indicated in Table 4. Further, the weight per thousand bluegills ranged from 0.6 pound (Pond 1) to 38.7 pounds (Pond 5). In Pond 5, which was stocked with the smallest number of bluegills per acre, the growth rate was faster than in any of the other ponds (Table 4, Fig. 2). It should be mentioned here that at the end of the first summer there were fewer bluegills in Pond 4 than in Pond 5. However, in addition to the 419 bluegills recovered per acre from Pond 4 in October 1941, there were nearly 4,000 Iowa darters. Although probably not in direct competition for food with the bluegills, the darters presumably increased

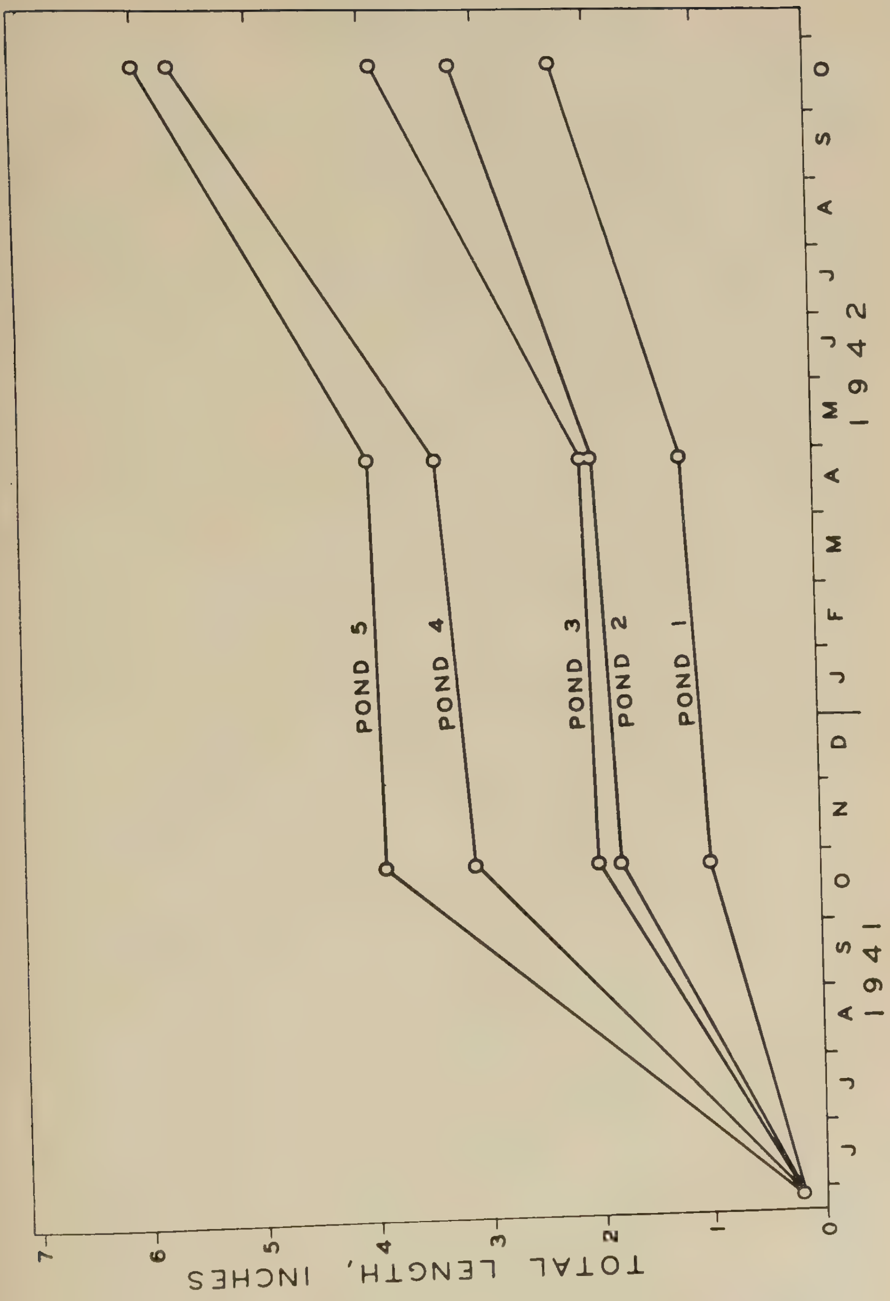

FIGURE 2.—Growth of bluegill yolk fry in five ponds at the Wolf Lake Hatchery, as indicated by the average total length of the fish in the entire population at the end of the first summer (October 1941), the first winter (April 1942), and the second summer (October 1942). Ponds 1 and 2 were stocked at the same rate but Pond 1 was fertilized and Pond 2 was not.

TABLE 4.—*Sizes measured in total length (inches) and in weight per thousand individuals (pounds) of bluegills in five ponds at the Wolf Lake Hatchery*

igures are given for the end of the first summer (October 1941), the first winter (April 1942), and the second summer (October 1942) together with the percentage i creases in length and weight in each pond during the first winter and second summer]

d	Number stocked per acre	Average weight (pounds per thousand)						Average total length (inches)					
		May 1941	October 1941	April 1942	Percentage increase October 1941–April 1942	October 1942	Percentage increase April 1942–October 1942	May 1941	October 1941	April 1942	Percentage increase October 1941–April 1942	October 1942	Percentage increase April 1942–October 1942
	323,333	—[1]	0.6	0.9	50.0	6.6	633.3	0.20	1.0	1.2	20.0	2.3	91.7
	323,333	—[1]	3.6	4.7	30.6	17.1	263.8	0.20	1.8	2.0	11.1	3.2	60.0
	118,454	—[1]	4.1	5.8	41.5	32.1	453.4	0.23	2.0	2.1	5.0	3.9	85.7
	23,638	—[1]	21.1	24.1	14.2	134.9	551.0	0.23	3.1	3.4	9.7	5.7	67.6
	2,452	—[1]	38.7	39.4	1.8	145.2	268.5	0.23	3.9	4.0	2.6	6.0	50.0

ss than 0.01 pound per thousand

the demand to such an extent that the individual food supply per bluegill was not as great as that in Pond 5 where no fish other than the 892 bluegills per acre were present. Consequently, the fish in the latter pond grew more rapidly and to a larger size during the first summer.

The fish in Ponds 1 and 2, although stocked at the same level, grew at considerably different rates during the first summer. In Pond 1, which had been treated with fertilizer, the survival rate was more than twice that in Pond 2, whereas the rate of growth in length was only slightly more than half that in Pond 2. Even though the total food supply was more abundant in Pond 1, presumably due to the action of the fertilizer and indicated by the high rate of survival, the supply for each individual fish throughout the summer was apparently not as great as that in Pond 2. Then, too, the competition for space may have been an important factor in controlling the growth of the fish. In Pond 1 the bluegills weighed only 0.6 pound per thousand individuals at the end of the first summer (Table 4) whereas those in Pond 2, although less than twice as long on the average, weighed six times as much.

In Pond 3, which had been stocked at a rate intermediate to those of Ponds 2 and 4, the growth of the bluegills in length and weight, although it approached that in Pond 2 more closely, was between those of Ponds 2 and 4.

The average lengths and weights of the fish in all five ponds increased during the winter. Increases in length ranged from 2.6 percent (Pond 5) to 20.0 percent (Pond 1) with corresponding increases in weight ranging from 1.8 percent (Pond 5) to 50.0 percent (Pond 1). The observed increases in average length and weight may have been caused by selective mortality which eliminated more small fish. It is more probable, however, that apparent growth is a combination of real growth and some selection.

During the second summer the bluegills in all ponds increased 50 percent or more in average length and more than 250 percent in weight. The bluegills in Pond 5, which grew most rapidly during the first summer, were very nearly overtaken by those in Pond 4 (Table 4). In the latter pond the fish increased in average length from 3.4 inches in April 1942 to 5.7 inches the following October, and in average weight from 24.1 pounds per thousand to 134.9 pounds per thousand. During the same period the bluegills in Pond 5 increased an average of 2.0 inches in length and from 39.4 pounds to 145.2 pounds per thousand. The rapid increase in rate of growth shown by fishes of Pond 4 is attributed to the smaller population (202 fish per acre, April 1942).

It is of interest to note here that the bluegills in Ponds 4 and 5 spawned during their second summer of life. On June 29, 1942, a total of 331 bluegills beds were counted in Pond 5 and 29 such beds were observed in Pond 4. It is not known whether all those nests contained eggs or fry at that time. However, when the ponds were drained in October 1942, only 5,125 young bluegills were recovered from Pond

5, whereas 22,321 were taken from Pond 4. Examination of the stomachs of 60 adult bluegills from Pond 5 revealed that 27 of them (45 percent) contained small bluegills. No small bluegills were found in the stomachs of 30 adults recovered from Pond 4. This cannibalism, which is not so frequently noticed among bluegills as among some other hatchery-reared fish (notably the black basses and yellow pikeperch), reduced the population of young bluegills in Pond 5 to a great extent.

When the ponds were drained in October 1942, and the experiment terminated, all the adult bluegills from Ponds 4 and 5 were measured, weighed, and sexed. Of the 618 fish taken from Pond 5, 365 (59 percent) were males and 253 (41 percent) were females (sex ratio of 144 males to 100 females). The size range of those males extended from 115 to 184 millimeters (4.53 to 7.24 inches) with an average of 155.7 millimeters (6.13 inches), whereas the females ranged in length from 130 to 173 millimeters (5.12 to 6.18 inches) with an average of 146.5 millimeters (5.77 inches). Thus, there was a difference in average length of 9.2 millimeters (0.36 inch) between the adult male and female bluegills in Pond 5 at the end of 17 months. In Pond 4, where 181 bluegills were recovered in October 1942, 78 fish (38 percent) were males and 103 (62 percent) were females (ratio of 76 males to 100 females). The males ranged in length from 115 to 187 millimeters (4.53 to 7.20 inches) with an average length of 152.5 millimeters (6.00 inches) and the lengths of the females ranged from 120 to 170 millimeters (4.72 to 6.70 inches) and averaged 138.8 millimeters (5.46 inches). The differences between the average total length of the males and females from Pond 4 was 13.7 millimeters (0.54 inch) at the end of the 17-month period. In each pond the size range of the males was considerably greater than that for the females and the size ranges for the fish of each sex correspond closely in both populations.

These data on the differences in growth of male and female bluegills are in accord with those of other workers. Hubbs and Hubbs (1933), Hubbs and Cooper (1935), and Bailey and Lagler (1938) found that growth in length was about the same in both sexes during the first year of life for bluegills, green sunfish, and longear sunfish (*Lepomis megalotis*) and that the males usually grew more rapidly than the females after they were a year old (second summer of life).

Between April 1942 and the following October, the bluegills in Pond 1 increased in length from 1.2 to 2.3 inches and in weight from 0.9 to 6.6 pounds per thousand individuals. During that same period the fish in Pond 2 grew from 2.0 to 3.2 inches in length and showed an increase in weight from 4.7 to 17.1 pounds per thousand. Here, again, the increased competition for food in the denser population in Pond 1 kept the fish from overtaking those in Pond 2 even though the food supply in Pond 1 had been increased through fertilization. None of the fish in either of those populations spawned.

In Pond 3, where the green sunfish increased tremendously in number and weight during the second summer, the bluegills grew rapidly, increasing from 2.1 to 3.9 inches in length and from 5.8 to 32.1 pounds per thousand in weight.

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FISH POPULATIONS IN SOME MINNESOTA TROUT STREAMS

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Abstract

Fish populations were checked in three Minnesota trout streams by the electrical-shock method. Total weights of fish per acre varied from an average of 251.1 pounds in 18 streams of the Root River system to 50.3 pounds in the North Shore system. Trout (brook, brown, and rainbow) varied from 17.3 percent of the total in the former system to 72.0 percent in the latter. The structure of the trout population in the northern streams showed more or less normal size distribution but in the other systems 6- to 9-inch trout predominated almost to the exclusion of the smaller fish. It is presumed that in the latter streams most fish are derived from planted stock.

Introduction

Accurate information on the nature and abundance of fish populations at various seasons is essential to good trout-stream management. Such data should include weights, numbers, and size distribution of all species so that natural reproduction, the interrelationships of various groups of fishes, and general stream productivity can be determined. Solution of fundamental problems in stream economy can thereby be made and translated into practical fishery management.

Various methods have been employed to secure complete estimates of stream populations (Haskell, 1940; Haskell and Zilliox, 1941; Hoover, 1938; Shetter and Hazzard, 1939). In 1944, 1945, and 1946, efforts to obtain such estimates on three Minnesota trout-stream systems were made. Two of these systems, the Root and the Whitewater, lie in southeastern Minnesota and discharge into the Mississippi River just above the Iowa-Minnesota border. They differ greatly from the North Shore system of 28 major streams which empty into Lake Superior. The Root and Whitewater systems are adjacent and together include 1,500 miles of streams that drain a basin 40 by 70 miles in greatest dimension and 2,000 square miles in area. From the headwaters to their points of discharge into the Mississippi they fall approximately 800 feet. The fertile glaciated and loess soils of the region overlie thick limestone and sandstone formations into which deep valleys have been cut by water action. All of the streams are spring-fed, have sand, rubble, or silt bottoms, and are moderately shaded. In periods of normal flow the water is hard, with total alkalinities ranging from 140.0 to 250.0 p.p.m. and pH values varying from 8.0 to 8.6.

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The severe erosion of the watershed has been hastened by intensive cultivation of valleys and surrounding uplands. It has resulted in the filling of the streams with sand and the accumulation of deep silt deposits in some flood-plain areas. Flood crests of 4 to 20 feet above normal levels sweep through stream channels during spring runoff and after severe rainstorms. In 1946 some streams sustained three to four such freshets.

The North Shore watershed is rugged and steep with infertile glaciated soils, large pre-Cambrian rock outcrops, and deep gorges. Most streams pass over precipitous falls during their 1,300-foot fall from source to mouth. These waters are moderately hard with carbonate contents of 20.0 to 85.0 p.p.m. and pH values from 6.5 to 7.5. Since stream flow is dependent on surface runoff and drainage from bogs and headwater lakes, it is erratic and responds directly to the volume of rainfall. Disastrous fires during the past 30 years have reduced the influence of the headwater muskegs which are the chief sources of cool, steady water flow.

EQUIPMENT AND METHODS

The electrical-shock method (Burr, 1931; Hager, 1934) was used in the Minnesota studies to secure population samples. A portable 500-watt, alternating-current generator adjusted to deliver 175 volts provided electrical energy. Two portable electrodes were designed to create the most effective electric field across relatively wide streams and still be useful in deep holes.

Streams 50 feet wide with holes 8 feet deep were sampled successfully by blocking off 100- to 300-yard sections of the channel with ¼-inch seines and moving the energized electrodes up and down the stream margins until all fish were removed. The fish so taken were weighed, measured, and replaced in the stream above the test sectors. Small and large fish seemed equally susceptible to shock but the smaller fish took less time to recover. A very few fish, mostly common suckers, were killed by the shock.

Data were collected separately on each of three trout species, white suckers, and the four most important kinds of trout-stream forage fishes. Numbers and weights of the less common minnows and darters were lumped. Information from all sectors of each stream was combined and the weight of fishes computed in terms of pounds per acre. Such a procedure often obscures significant facts but it permits a condensation of voluminous data sufficiently to make useful generalizations possible.

Although the electrical-shocking method of collecting population data is extensively used and well standardized, sampling techniques vary widely. If the inaccessibility of certain areas prevents the examination of the entire stream, random sections must be taken. In Minnesota studies random samples chosen by variations of the method proposed by Mottley

TABLE 1.—*Standing population of trout, white sucker, and all other species in test sections of Root River tributaries during 1945*

Stream	Area of test sections (square feet)	Total weight of all fish (pounds/acre)	Trout[1]		White sucker		Other fish	
			Pounds per acre	Percentage of total weight	Pounds per acre	Percentage of total weight	Pounds per acre	Percentage of total weight
Thompson Creek	36,543	103.41	11.59	11.3	75.76	73.7	16.06	14.9
Dexter Creek	16,704	229.39	15.26	6.7	190.75	83.4	23.38	9.9
Silver Creek	3,460	118.38	11.58	9.8	44.52	37.6	62.28	53.6
South Fork	21,313	340.25	41.54	12.2	275.80	81.1	22.91	6.7
East Beaver	26,959	171.37	70.25	41.0	47.03	27.4	54.94	31.6
Wisel Creek	21,071	272.08	35.30	12.0	191.55	70.4	45.23	16.9
Money Creek	11,395	110.73	5.51	5.0	53.97	48.3	51.25	46.6
Rush Creek	5,592	415.71	17.65	4.2	155.31	37.5	242.75	58.3
Pine Creek	9,706	547.21	69.26	12.6	346.54	63.3	131.41	24.1
Gribben Creek	10,604	155.10	52.83	34.0	34.73	22.4	67.54	43.6
South Branch	7,030	338.12	52.86	15.4	203.41	60.6	81.85	25.0
Duschee Creek	12,876	264.04	60.59	23.1	154.38	58.9	49.05	17.9
Watson Creek	15,541	109.11	33.21	31.1	59.06	55.5	16.84	13.0
North Branch	24,252	289.21	111.96	38.7	170.68	58.9	6.57	2.4
Trout Creek	30,603	283.03	68.36	23.6	192.10	66.5	27.57	9.8
Rice Creek	8,305	91.10	14.04	15.4	31.77	34.9	45.29	49.6
Mill Creek	10,950	343.07	14.49	4.2	150.84	43.9	177.74	51.9
Upper Bear	13.544	338.11	37.31	11.1	121.58	35.9	179.22	53.0

[1] Includes brook, brown, and rainbow trout

(1942) were tried first. Care was taken to include a good pool and typical riffle area in the 100- to 150-yard test section. In later work attempts were made to sample as much of the entire stream as possible by passing one block seine over another until all trout waters had been covered. By working 17 to 98 percent of the total area of streams varying in length from 2 to 11 miles errors of random sampling were minimized.

FISH PRODUCTION OF ROOT RIVER TRIBUTARIES

Fish populations at 69 stations in 18 streams were examined during 1945 (Table 1). The total areas covered in the different streams ranged from 3,460 square feet in Silver Creek to 36,543 square feet in Thompson Creek. Standing crops of fish varied from a total of 91.1 pounds per acre in Rice Creek to 547.2 pounds in Pine Creek. Of these total weights, trout comprised 4.2 to 41.0 percent, white suckers 22.4 to 83.4 percent, and all other fish 2.4 to 58.3 percent in the various streams. The average total fish crop of all streams in the watershed was 251.1 pounds per acre of which common suckers made up the greater portion (Table 2).

TABLE 2.—*Total weight (pounds per acre) of fish in three Minnesota stream systems and average weight of trout, suckers, and other fish*

[Expressed as percentage of total weight of standing fish populations]

Stream system	Average population of all streams (pounds/acre)	Percentage of total weight		
		Trout	Suckers	Other fish
Root .... (18 streams)	251.1	17.3	55.3	29.4
Whitewater .... (4 streams)	121.9	9.3	60.9	29.8
North Shore ...... (3 streams)	50.3	72.0	5.6	22.3

Of the 698 trout taken at all stations, 644 were brown trout (*Salmo trutta fario*), 48 were brook trout (*Salvelinus f. fontinalis*), and 6 were rainbow trout (*Salmo gairdnerii irideus*). These returns are roughly comparable to the relative rates at which the three species have been stocked. North Branch Creek with an average of 112 pounds per acre had the greatest trout population. This stream likewise had the greatest number of trout per mile with an average of 934 fish. The grand average standing crop of trout in the Root River tributaries was 43.4 pounds per acre.

Production of white suckers (*Catostomus c. commersonnii*) ranged from 31.8 pounds per acre in Rice Creek to 346.5 pounds per acre in Pine Creek, with the maximum crop in some individual stretches greatly exceeding these weights.

Data on standing crops of four important minnows and other fishes are of value not only to determine availability of trout foods but also to show quantities of minnows which may be obtained from trout waters for other purposes (Table 3). The two species of sculpins (*Cottus cognatus* and *Cottus b. bairdii*) were found in only eight streams and their abundance varied greatly. These forms, especially *Cottus cognatus,* usually are considered to be indicators of stream conditions suitable for trout, but this relationship did not always hold in Root River tributaries. All eight streams which contained sculpins carried trout, but Duschee, Watson, and North Branch creeks all contained heavy trout populations but few or no sculpins.

TABLE 3.—*Standing crops of minnows and other fish in 18 Root River tributaries*

[Expressed in pounds per acre]

Stream[1]	Sculpins[2]	Longnose dace[3]	Stoneroller[4]	Creek Chub[5]	Other Fish[6]
Thompson Creek . .	–	9.70	–	6.17	0.19
Dexter Creek	–	14.82	–	8.55	0.01
Silver Creek	–	4.14	2.33	57.62	0.19
South Fork	14.98	4.86	–	2.88	0.19
East Beaver	14.49	2.62	–	9.44	0.94
Wisel Creek	0.09	9.71	8.43	5.36	20.82
Money Creek	–	23.00	–	10.58	17.67
Rush Creek	–	37.61	154.80	36.09	14.25
Pine Creek	2.78	23.24	37.10	26.81	41.48
Gribben Creek	3.92	2.30	47.26	11.74	2.32
South Branch	4.18	6.42	28.21	11.72	31.32
Duschee Creek . . .	–	11.70	19.56	14.28	2.79
Watson Creek	–	14.88	1.46	–	0.50
North Branch	6.15	0.29	0.09	–	0.04
Trout Creek	19.05	8.05	0.10	–	0.37
Rice Creek	–	13.65	19.37	5.45	8.83
Will Creek	–	13.13	116.50	26.96	21.15
Upper Bear	–	13.18	112.04	36.12	17.88

[1] Number of stations and total areas sampled are same as in Table 1

[2] Includes *Cottus cognatus* and *Cottus b. bairdii*

[3] *Rhinichthys c. cataractae*

[4] *Campostoma anomalum pullum*

[5] *Semotilus a. atromaculatus*

[6] Includes *Entosphenus* ammocoetes, *Hypentelium nigricans, Nocomis biguttatus, Notropis cornutus frontalis, N. d. dorsalis, N. spilopterus, N. umbratilis cyanocephalus, Phenacobius mirabilis, Clinostomus elongatus, Ameiurus m. melas, Noturus flavus, Poecilichthys exilis, Catonotus flabellaris lineolatus, Boleosoma n. nigrum,* and *Lepomis cyanellus*

The creek chub is (*Semotilus a. atromaculatus*) is common in Minnesota trout streams but rarely attains any degree of numerical abundance. Occurrence of stone-rollers (*Campostoma anomalum pullum*) in great numbers indicates that a stream is too warm or too muddy for high production of trout. The greatest crop of this minnow in the streams checked was 154.8 pounds per acre from Rush Creek, but higher abundance probably occurs in other streams which cannot support trout. Only the longnose dace (*Rhinichthys c. cataractae*) was found in all streams. Its

TABLE 4.—*Standing population of trout, white sucker, and all other species in test sections of Whitewater tributaries during 1946*

Stream	Area of test sections (square feet)	Total weight of all fish (pounds/acre)	Trout[1]		White sucker		Other fish[2]	
			Pounds per acre	Percentage of total weight	Pounds per acre	Percentage of total weight	Pounds per acre	Percentage of total weight
South Branch	305,256	134.99	15.65	11.6	102.99	76.3	16.33	12.1
Middle Branch	174,391	106.43	6.70	6.3	78.54	73.8	21.17	19.9
North Branch	259,662	125.82	6.66	5.3	93.25	74.5	25.91	20.6
Beaver Creek	43,585	120.19	16.59	13.8	22.60	18.8	81.01	67.4

[1] Includes brook, brown, and rainbow trout

[2] Includes *Cyprinus carpio, Rhinichthys c. cataractae, R. atratulus meleagris, Semotilus a. atromaculatus, Notropis cornutus frontalis, Hyborhynchus notatus, Pimephales p. promelas, Chrosomus erythrogaster, Campostoma anomalum pullum, Boleosoma n. nigrum, and Cottus cognatus*

TABLE 5.—*Standing population of trout, white sucker, and all other species in test sections of North Shore streams*

Stream	Area of test sections (square feet)	Total weight of all fish (pounds/acre)	Trout[1]		White sucker		Other fish[2]	
			Pounds per acre	Percentage of total weight	Pounds per acre	Percentage of total weight	Pounds per acre	Percentage of total weight
Caribou River	15,462	38.82	29.77	76.7	3.82	0.1	8.88	22.9
Manitou River	33,744	6.57	2.85	43.4	1.09	16.7	2.62	39.9
French River	72,766	105.43	101.2	96.0	0.00	0.0	4.21	4.0

[1] Includes brown and brook trout in abundance, rainbow less commonly

[2] Includes *Semotilus a. atromaculatus, Margariscus margarita nachtriebi, Rhinichthys atratulus meleagris, R. c. cataractae, Cottus cognatus*

abundance varied from 0.29 pound per acre in North Branch Creek to 37.6 pounds in Rush Creek.

Although forage and other small fish, excluding suckers, outweighed the trout in most Root River tributaries and were second only to suckers, in 5 of the 18 streams these fishes made up at least half of the population by weight. Such streams were usually warm, sandy creeks supporting a low weight of trout. There is some evidence of lower forage-fish yields from streams supporting heavy populations of trout which fact may indicate predation by trout or less favorable habitat. Available information also indicates a steady decrease in the total quantity of fishes, especially trout, from the middle sections of the creeks to their mouths.

FISH PRODUCTION OF WHITEWATER TRIBUTARIES

Trout-carrying portions of all four branches of the Whitewater system were sampled in 1946. The total area examined in each stream and the percentage of the total stream covered were greater than in the previous year on Root River tributaries (Table 4). Fish populations varied from 106.4 pounds per acre in the Middle Branch to 134.9 pounds per acre in the South Branch. The weight of trout ranged from 6.6 to 16.6 pounds per acre and, although total standing crops were not as great in the Whitewater as in the Root River system, the weights of trout, sucker, and other fish were in the same relative proportions (Table 2).

FISH PRODUCTION OF NORTH SHORE STREAMS

In the North Shore system, the Caribou and Manitou Rivers were examined during 1944 and French River during 1946. The area sampled in each stream was not as great as in some southern waters (Table 5) because all streams are much less accessible.

The most outstanding differences between fish production in North Shore streams and southeastern streams are that standing crops are lower in the northern section than in some southern streams and that trout comprise a larger proportion of the fish population in the northern region (*cf.* Tables 2 and 5). Suckers are scarce in all northern streams and the weights of other forage fish which consist mostly of longnose dace and sculpins are a poor second when compared with those of trout. In some streams brown trout decline in importance and are surpassed by brook trout. Rainbow trout are scarce chiefly because they are not stocked and because cataracts at the lower ends of these streams deny the migratory rainbows re-entry once they have dropped down into Lake Superior.

COMPARISON OF STANDING CROPS IN MINNESOTA WITH THOSE OF OTHER REGIONS

Standing crops of fish in trout streams have been determined in New Hampshire by Hoover (1938) using seines, in New York by Haskell (1940) using a shocker of different design from Minnesota equipment,

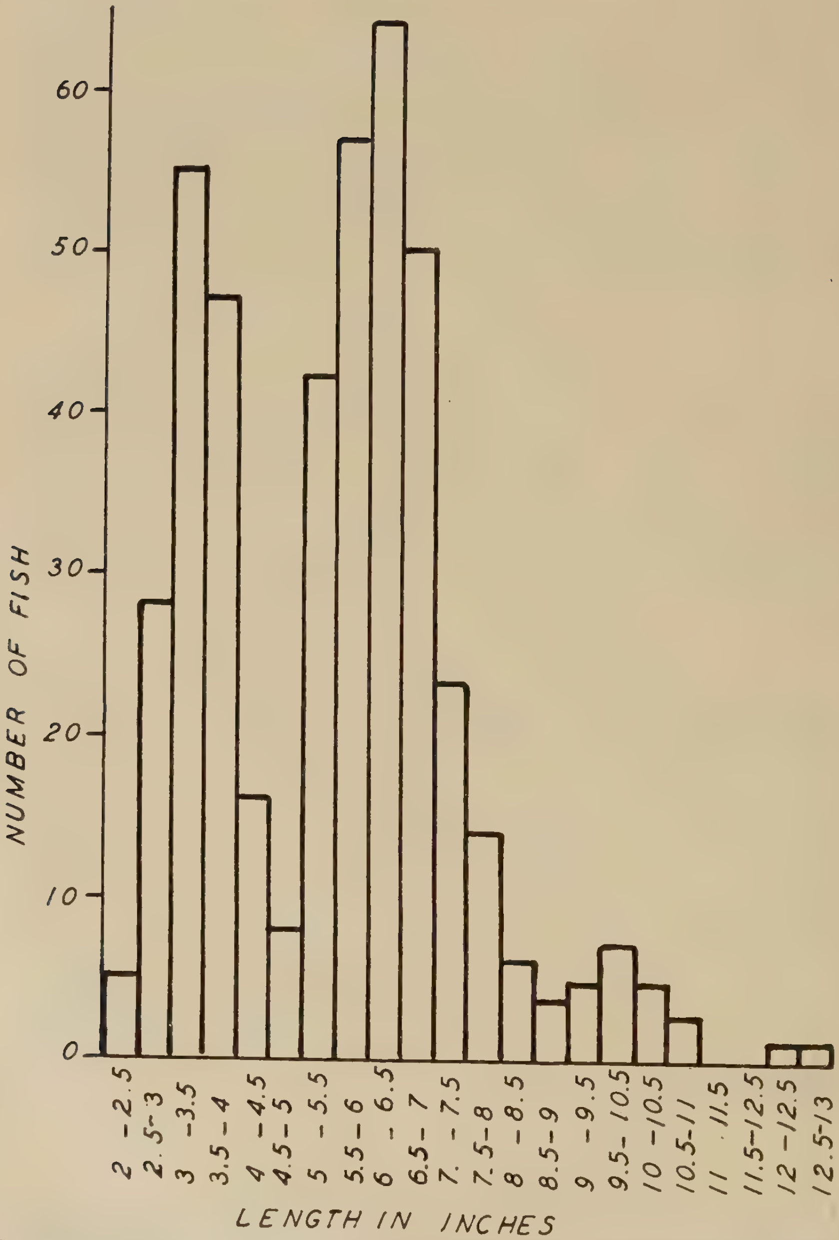

FIGURE 1.—Length frequency of a population of 436 brook trout taken from French River, August 1946.

in streams of lower Michigan by Shetter and Hazzard (1938) and Shetter and Leonard (1943), and in New York by Schuck (1945). Many similar investigations have been undertaken in other states but are not yet reported.

In comparison with trout streams in other areas, southeastern Minnesota streams have much higher total weights of fish but smaller crops of trout. North Shore streams have populations comparable in size and make-up to those of the six primitive brook trout streams studied by Hoover (1938) in New Hampshire.

STRUCTURE OF TROUT POPULATIONS

It was not practical during the progress of field work to take scale samples from every trout for age and growth studies and still return the fish to the streams in good condition. In consequence length-frequencies based on total lengths of all trout captured have been compiled to give a picture of population structure. Two general types of population have been observed in Minnesota streams. One, which is characterized by a more or less normal distribution of sizes (Figure 1) is typical of North Shore streams but is found in only 3 of the 22 Root and Whitewater tributaries examined. Of the two large modes, the one representing shorter fish is probably composed of naturally reared young and the larger is made up of naturally produced fishes bolstered by annual plantings of yearlings. The second type (Figure 2) which is characteristic of most southeastern Minnesota streams has one length-frequency mode between 6 and 9 inches and a scattering of larger fish. It appears that in such a population there is no natural reproduction, most of the fish are of a length corresponding exactly to that of planted yearlings, and a very low rate of survival exists from one year to the next. This condition may result from

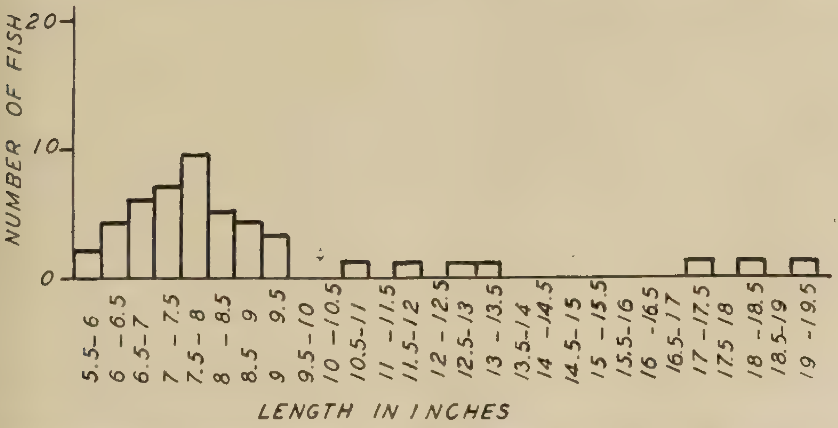

FIGURE 2.—Length frequency of 48 brown trout taken from the South Fork of Root River, July 1945.

heavy floods, lack of shelter and good pools, and relatively heavy stocking of catchable-sized fish.

The data already secured on Minnesota streams indicate the necessity of complete information on populations in areas where intensive management is contemplated. In consequence a series of experiments and further investigation is now underway in typical streams.

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THE AGE, GROWTH, AND DISTRIBUTION OF THE LONGJAW CISCO, *LEUCICHTHYS ALPENAE* KOELZ, IN LAKE MICHIGAN

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Abstract

The longjaw (*Leucichthys alpenae*) was found at all of the 109 stations fished in the open lake during 1930–1932 and at 29 of the 32 stations in Green Bay in 1930 and 1932. Koelz (1929) found the longjaw at 35 localities, 33 of which were different from those fished in 1930–1932. The species was most abundant in water with a depth of less than 70 fathoms, but was found as deep as 97 fathoms. The longjaw was estimated to be about 4 1/3 times as abundant along the east shore of southern Lake Michigan as along the west shore in 1930 and 1931. The abundance along the east shore in 1930–1931 was estimated to be approximately equal to that in northern Lake Michigan in 1932. The best explanation for the relative scarcity of *L. alpenae* along the west shore is that a more intensive fishery, with smaller sizes of mesh, was operating on a separate population.

The length distribution of 6,954 specimens taken in 1930–1932 revealed little difference in frequencies between the sexes, the samples taken in each of the years 1930 and 1931, or the fish taken on the two shores of the southern region. The individuals caught in 1932 from northern Lake Michigan averaged 12.5 inches, total length, and were from 1.0 to 1.3 inches longer than fish taken by the same sizes of mesh from the southern area in 1930–1931.

Of the 378 longjaws whose ages were determined, 320 were taken during the summer of 1923 in northeastern Lake Michigan, and 58 were secured off Grand Haven, Michigan, in November 1928. The age groups represented ranged from II to IX. Age-group IV dominated in the 1923 samples making up 53.8 percent of the total, and age-groups III and V with 20.9 and 10.6 percent, respectively, were the next best represented groups. The III group dominated the 1928 collection with 55.2 percent of the total, and age-groups IV and II, that were represented by 31.0 and 12.1 percent, respectively, were the only other well represented groups.

The sexes grew at approximately the same rate. A total length of 11.1 inches and a weight of 6.4 ounces were reached at the end of 4 years of growth by the longjaws in northeastern Lake Michigan. The fish from Grand Haven averaged 11.0 inches, total length, and 6.1 ounces at the end of 4 years. Growth in length was most rapid during the first year and decreased continuously thereafter through the fourth year (fifth year in 1928). The increments in length of the 1923 fish during the fourth through the eighth years were approximately the same. Growth in weight of the fish taken in 1923 was computed to be most rapid following the fifth year of life. Growth compensation occurred among the longjaws of Lake Michigan. The major part of the annual growth in length had taken place before June 15, 1923.

Although the empirical data on the length-weight relationship of 5,314 fish failed to fall along a simple curve, it is believed that the following equation is the one best suited to computing the weight of the longjaw: $W = 0.96288 \times 10^{-5} L^{3.06060}$.

The coefficient of condition (K) of all longjaws increased as the standard length increased to 194 millimeters. The values then remained high up to 225 millimeters but decreased progressively until the fish reached a length of 265 millimeters. The coefficient changed little at fish lengths of 265 to 284 but began to increase again at 285 millimeters. Condition was best in 1931 and poorest in 1932. The individuals of both sexes were in the poorest condition during some month previous to August each year. Although the females were somewhat heavier in relation to their length than the males in practically all months, the weighted averages of K for all males and all females were almost identical (1.30 for the males and 1.31 for the females).

The sex ratio was determined from 7,457 individuals taken in 1930–1932 and 373 of the 1923 and 1928 specimens whose ages were determined. The percentage of females was relatively low in May 1931 and relatively high in October, but in the other months it remained more or less constant. In 1932 the females tended to become relatively less abundant in each month from April through September. There was little difference between the relative abundance of the sexes in 1930 and 1931 (72.4 percent females in 1930 and 67.5 percent in 1931). The consistently slightly higher percentage of females each month in 1932 (average of 80.6) probably represents a difference between populations. The relative abundance of the males decreased as the age increased. A natural differential mortality is suggested as the cause for the more rapid disappearance of the males.

Females may contain ripe eggs as early as July 9, and some females may spawn as early as October 16 despite the fact that the spawning season is in November.

INTRODUCTION

This study is a part of the extensive investigation of the chub fishery in Lake Michigan conducted jointly by the former U. S. Bureau of Fisheries (now incorporated in the Fish and Wildlife Service) and the Michigan and Wisconsin Departments of Conservation during the years 1930–1932. Seven species of chubs occur in Lake Michigan. Because they usually are marketed together, they are not separated in the statistics of catch. The longjaw, the largest of the chubs, inhabits only Lakes Michigan and Huron. It may be recognized by its pale color; long, heavy mandible (lower jaw) which usually extends beyond the maxillary (upper jaw); moderate length of paired fins; and large number of gill rakers on the first branchial arch. The species spawns in November. (See Koelz, 1929, for detailed taxonomic description and comparisons with other species in the genus.)

Nothing has been published on the food, migration, age, and growth of the longjaw in Lake Michigan. Van Oosten (1929a) presented data on the numbers taken by gill nets with meshes of various sizes, and Koelz (1929) discussed the geographic and bathymetric distributions, relative abundance, and spawning of the species.

I am greatly indebted to Dr. John Van Oosten, Chief, Great Lakes Investigations, U. S. Fish and Wildlife Service, for many valuable suggestions and for critically reviewing the manuscript and to Dr. Ralph Hile, Aquatic Biologist, U. S. Fish and Wildlife Service, for his many helpful suggestions during the course of the study. The 1930–1932 data were collected under the field supervision of Dr. H. J. Deason, Chief,

Office of Foreign Activities, U. S. Fish and Wildlife Service, who also prepared the original drawing from which Figure 1 was adapted.

MATERIALS AND METHODS

Of the 378 specimens used for the determination of age and the computation of growth, 320 were collected by Koelz in 1923 from the catch of 2¾-inch-mesh commercial gill nets fished in the northeastern section of Lake Michigan, and 58 were taken by Van Oosten in 1928 from 2½- and 2¾-inch-mesh gill nets set off Grand Haven, Michigan, in the southern part of the lake. The lengths of the fish in the 1923 sample, which were measured after some 20 years in preservative, were corrected for shrinkage by the factor 1.019.

The other phases of this study are based primarily on material collected from experimental gill nets by the scientific staff aboard the U. S. Fishery Vessel *Fulmar* during the years 1930, 1931, and 1932. Five sizes of mesh (2⅜, 2½, 2⅝, 2¾, and 3 inches, stretched measure as manufactured) were used in the linen gill nets fished in 1930 and 1931, except that in Green Bay during late September and early October 1930 only the three smaller sizes were fished. Only the three intermediate sizes of mesh were used in 1932, except that the 2⅜-inch mesh was fished also for a short time in Green Bay during the early spring. Each net was 510 feet long and 5 feet deep. All nets were set on the bottom.

The length-weight relationship was determined for 5,314 specimens caught at many localities distributed generally throughout the shallower water of the lake. (See Fig. 1, solid circles.) The length-frequency distribution was obtained for 6,954 fish taken during the 3 years. The sex was determined for 373 fish taken in 1923 and 1928 and for 7,457 individuals examined in 1930–1932. (On some dates the sex and stage of maturity were determined without obtaining data on length and weight.) All of the collections in 1930 and 1931 were made on or south of a line from Frankfort, Michigan, to Kewaunee, Wisconsin, except those of late September and early October 1930, which were taken from Green Bay, and all of the collections of 1932 were made north of that line.

The length measurements were secured from fresh specimens in the field by holding a steel tape graduated in millimeters as nearly parallel as possible to the long axis of the body, except that those fish collected in 1923 were measured by means of dividers. The weights were recorded to the nearest quarter ounce in 1930 and in part of 1932 and to the nearest tenth ounce in 1931 and the remainder of 1932.

The scales examined and measured for the determination of age and the computation of growth were mounted on glass slides in the gelatin-glycerin medium described by Van Oosten (1929b), and examined at a magnification of × 40.7. Ages are designated by roman numerals equivalent to the number of annuli present on the scales. The lengths at the end of previous years of life were computed from the diameter measurements of the scales by the direct-proportion method.

TABLE 1.—*The average number of longjaws per gang of nets taken each month in each 10-fathom interval of depth of water from the three sections of Lake Michigan and Green Bay*

[The averages in the upper part of the table are based on the catches in southern Lake Michigan (1930-1931) from gangs that contained one net each with meshes of 2⅜, 2½, 2⅝, 2¾, and 3 inches, whereas those in the lower part of the table are based on the catches in southern (1930-1931) and northern Lake Michigan (1932) and Green Bay (1932) from gangs that contained only one net each of the three intermediate sizes of mesh. The numbers of gangs are given in parentheses]

Month	Section of lake	Depth fished (fathoms)	Depth interval (fathoms)								
			10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99
May	East shore....	28-80	..	..	38.7 (6)	12.0 (1)	30.0 (1)	..	5.0 (4)	..	..
	West shore ...	27-66	..	12.5 (2)	12.5 (4)	31.0 (4)	22.0 (4)	8.0 (2)	..	..	..
June	East shore....	28-75	..	68.0 (1)	62.8 (5)	21.3 (3)	94.0 (2)	36.7 (3)	..	..	..
	West shore ...	27-66	..	11.5 (4)	20.0 (4)	12.3 (11)	19.0 (4)	8.3 (7)	..	..	..
July	East shore....	23-75	..	117.2 (6)	..	40.8 (4)	42.3 (6)	19.6 (5)	..	..	..
	West shore ...	25-80	..	9.0 (1)	16.1 (7)	10.3 (3)	10.0 (4)	10.8 (5)	11.0 (2)	..	..
August	East shore....	23-78	..	94.6 (8)	103.0 (1)	..	40.8 (4)	23.7 (7)	..	..	..
	West shore ...	25-87	..	20.0 (1)	22.4 (13)	10.8 (5)	4.0 (2)	8.5 (4)	2.2 (11)	1.0 (6)	..
September	East shore....	27-92	..	17.0 (1)	79.0 (2)	63.0 (1)	41.3 (3)	27.7 (3)	1.0 (1)	..	..
	West shore ...	32-87	..	..	16.7 (6)	..	8.8 (4)	..	4.0 (3)	1.0 (2)	..
October	East shore....	29-90	..	..	214.4 (5)	214.0 (3)	34.0 (1)	57.0 (1)	16.0 (1)	..	..
	West Shore ...	32-97	..	..	28.9 (9)	27.7 (6)	14.0 (3)	..	6.5 (4)	5.5 (2)	6.7 (3)
November	West shore ...	16-75	19.0 (1)	..	37.2 (11)	66.8 (6)	..	..	9.1 (7)	..	..
April	Green Bay	14-18	0.2 (24)	..	..	..	..	..	..	..	..
May	Green Bay	14-19	2.3 (105)	..	..	..	..	..	..	..	..
June	East shore....	28-75	..	42.0 (1)	25.4 (5)	11.7 (3)	61.0 (2)	21.0 (3)	..	..	..
	West shore ...	27-66	..	4.5 (4)	9.5 (4)	3.8 (11)	8.8 (4)	4.0 (7)	..	..	..
	Northern	23-65	..	..	22.0 (6)	24.9 (22)	..	3.0 (7)	..	..	..
	Green Bay	16-24	2.7 (7)	4.9 (14)	..	..	..	..	..	..	..
July	East shore....	23-75	..	53.0 (6)	..	21.0 (4)	22.3 (6)	12.6 (5)	..	..	..
	West shore ...	25-80	..	7.0 (1)	6.7 (7)	5.0 (3)	5.8 (4)	5.0 (5)	6.0 (2)	..	..
	Northern	30-69	..	..	11.6 (18)	17.7 (18)	23.7 (81)	12.1 (13)	..	..	..
August	East shore....	23-78	..	58.4 (8)	58.0 (1)	..	17.0 (4)	10.0 (7)	..	..	..
	West shore ...	25-87	..	4.0 (1)	5.2 (13)	4.4 (5)	2.5 (2)	3.5 (4)	1.5 (11)	0.3 (6)	..
	Northern	17-73	..	...	12.1 (42)	23.7 (35)	23.4 (34)	10.8 (5)	..	..	..
September	East shore....	27-92	..	9.0 (1)	48.0 (2)	25.0 (1)	26.0 (3)	18.3 (3)	1.0 (1)	..	..
	West shore ...	32-87	..	..	7.0 (6)	..	4.2 (4)	..	1.0 (3)	0.5 (2)	..
	Northern	39-65	..	..	..	16.4 (22)	25.3 (26)	..	..	..	..

DISTRIBUTION AND ABUNDANCE

Koelz (1929) found the longjaw at 35 localities in 39 lifts mostly made by commercial fishermen. Only two of his stations were fished by the *Fulmar*. Longjaws were lacking in only two lifts Koelz examined from the open lake (both off Milwaukee, Wisconsin, near stations where *L. alpenae* was found in 1930–1931), but he found them in Green Bay only near the mouth where the water was deepest. The greatest abundance of the longjaw, when not spawning, was determined by Koelz to be in 28 to 70 fathoms with only stragglers found shallower and deeper. He found the extreme depth range of the species to be from 5 to 90 fathoms.

The data on the bathymetric distribution of the longjaw in Lake Michigan during 1930–1932 are presented in Table 1, which gives the average number of fish taken per gang of nets each month from each 10- fathom interval of depth of water and the range of depth in which the nets fished. The mean of the depths at the ends of a gang of nets was used as the depth in which the gang fished. The 1930 and 1931 data from the southern part of the lake have been combined, as preliminary tabulations showed no great or consistent differences.

The averages in the upper half of the table are based on the catch from gangs of five nets (one net each with meshes of 2⅜, 2½, 2⅝, 2¾, and 3 inches), whereas those in the lower half are based on the catch from gangs of three nets (one net each with meshes of 2½, 2⅝, and 2¾ inches). The west shore as used in this paper is composed of the waters of the States of Illinois and Wisconsin north to Kewaunee. The east shore includes the State of Michigan waters south of Frankfort. Northern Lake Michigan comprises the area north of a line extending from Frankfort, Michigan, to Kewaunee, Wisconsin, except Green Bay, which is treated separately.

The data are from specimens taken in 270 lifts of 745 gangs of nets at 132 stations. (When fish were scarce, two or more gangs, as defined above, were set in one string of nets.) The longjaw was present at all of the 109 stations fished in the open lake where the catch was identified and at 29 of 32 stations in Green Bay (including 9 stations fished in 1930 that are excluded from the table). (Fig. 1 shows only 107 stations for the open lake and 25 for Green Bay, because some of the stations were too close together to be shown separately at the scale used in the chart.)

Data obtained during late September and early October 1930 from Green Bay are not included in Table 1 because the gangs of nets used then were made up of one net each with meshes of 2⅜, 2½, and 2⅝ inches and are, therefore, not comparable to the gangs fished at any other time. Although not present at two stations, the longjaw was well represented at the other seven stations in Green Bay in 1930. The 41 gangs fished in 10–19 fathoms during late September averaged 12.8 longjaws per gang, and the 15 gangs fished at the same depth in early

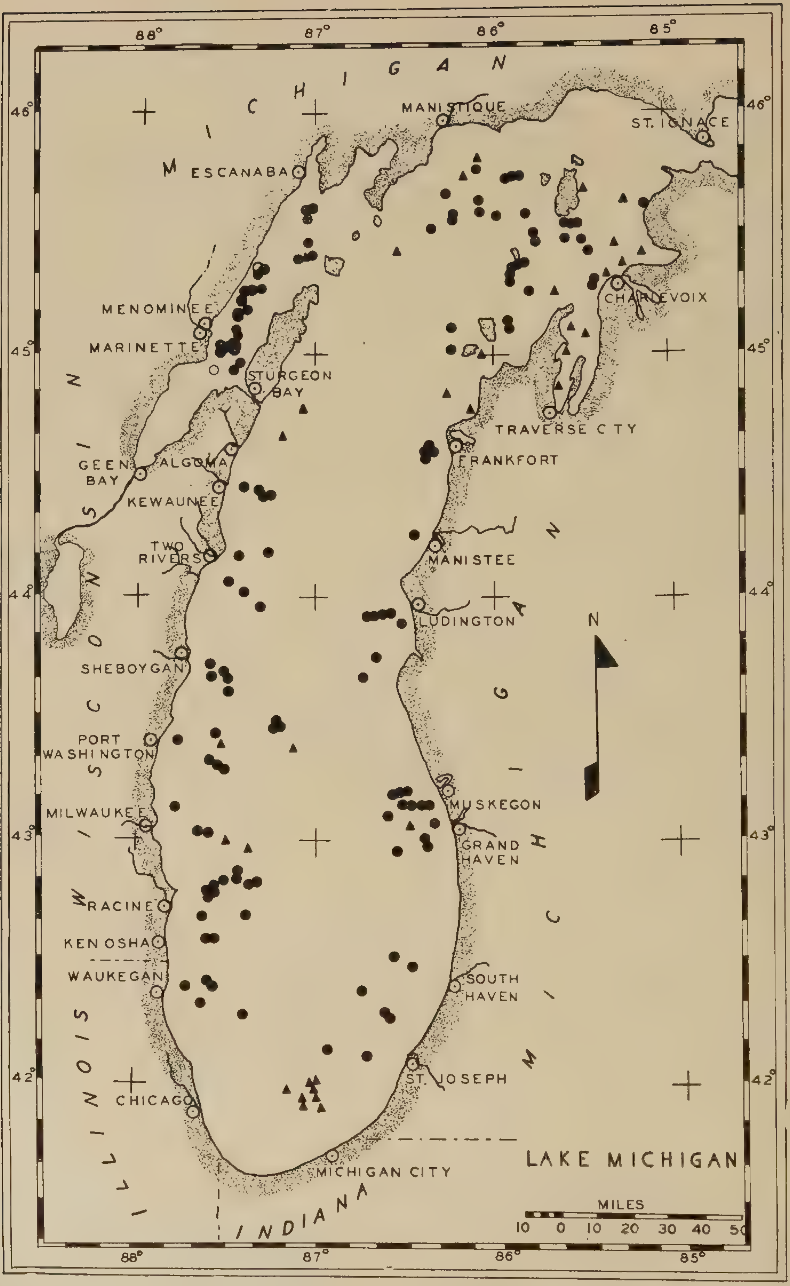
88°
87°
86°
85°
46°
45°
44°
43°
42°
MICHIGAN
MANISTIQUE
ST. IGNACE
ESCANABA
CHARLEVOIX
MENOMINEE
MARINETTE
STURGEON BAY
TRAVERSE CITY
FRANKFORT
GREEN BAY
ALGOMA
KEWAUNEE
TWO RIVERS
MANISTEE
LUDINGTON
N
SHEBOYGAN
WISCONSIN
PORT WASHINGTON
MILWAUKEE
MUSKEGON
GRAND HAVEN
RACINE
KENOSHA
WAUKEGAN
SOUTH HAVEN
ILLINOIS
ST. JOSEPH
CHICAGO
MICHIGAN CITY
LAKE MICHIGAN
MILES
10 0 10 20 30 40 50
INDIANA

FIGURE 1.—Distribution of the longjaw in Lake Michigan. Solid circles = stations at which the longjaw was taken, 1930–1932; open circles = stations at which the longjaw was not taken. 1930–1932; solid triangles = additional localities from which Koelz (1929) reported the longjaw.

October had an average catch of 49.2 longjaws. The species was only slightly less abundant during early October in 18–22 fathoms (20 to 29-fathom interval), where the six gangs averaged 43.8 longjaws per gang.

All of the data on the abundance of the longjaw in Green Bay, collected in different years and in various sizes of mesh (2⅜ inches in 1920—Koelz, 1929; 2⅜, 2½, and 2⅝ inchces in 1930; and 2⅜, 2½, 2⅝, and 2¾ inches in 1932), suggest a possible highly seasonal variation in availability. The species was scarce during April, May, and early June 1932, the average catch per gang varying from 0.2 to 2.7 fish (Table 1). Koelz found only an occasional longjaw on August 18, 1920. As reported above, in late September and early October 1930, the take per gang varied from 12.8 to 49.2 longjaws. The decided increase in abundance during September and October is suggestive of a prespawning concentration of longjaws in Green Bay.

The data in Table 1 show that the longjaw was rather widely distributed over all depths of less than 70 fathoms that were fished in southern Lake Michigan during the collecting seasons of 1930 and 1931, and that during July along the west shore there was a nearly uniform distribution to a depth of 79 fathoms. However, within this wide range of depth, the maximum number usually was found at some depth of less than 40 fathoms. There is little evidence of any mass shifting from one depth to another during the year. Along the east shore the greatest numbers of longjaws were taken from 30–39 fathoms in May, 50–59 fathoms in June, 20–29 fathoms in July, and 30–39 fathoms in August through October. Along the west shore the 10-fathom interval of depth of water producing the greatest number of longjaws was 40–49 in May and November and 30–39 in June through October. In some instances too few lifts were made for adequate comparisons and in others the difference between the average catch was very small. For example, in October the 40- to 49-fathom depth interval on both sides of the lake yielded practically as many longjaws per gang of nets as did the 30- to 39-fathom interval.

The longjaw appears to have been most abundant at depths of 40–49 fathoms in northern Lake Michigan in June, 50–59 fathoms in July, 40–59 fathoms in August, and 50–59 fathoms in September.

Only one lift was made in less than 20 fathoms in southern Lake Michigan and none in less than 30 fathoms in the northern section. At these two depths the longjaws appeared to have been rather abundant, and so it may be assumed that they must have occurred rather commonly in shallower water. They were relatively scarce at depths greater than 69 fathoms (79 fathoms on the west shore during July) in both the southern and northern waters, although the maximum depth of occurrence was 97 fathoms. These conclusions agree well with those of Koelz (1929), who found the longjaw in greatest abundance at a depth range of 28–70 fathoms and took them in depths as great as 90 and as shallow as 5 fathoms. The species was found to be generally distributed in Green

Bay north of a line from the Sturgeon Bay ship canal to Marinette, Wisconsin, in 1930 and 1932.

The data in Table 1 afford also an opportunity to compare the relative abundance of the longjaw in the different sections of the lake. The abundance in each of the three sections was estimated from the average number of fish taken by comparable gangs of nets fished in the same depth of water at the same time. For example, in May the sum of the average number per gang in depths of 30–59 fathoms was 80.7 on the east shore and 65.5 on the west shore (Table 1). The ratio of fish on the east shore to those on the west shore was 80.7/65.5 or 1.23 to 1. Similarly, the sum of the average catches in the five depth intervals in June was 282.8 on the east shore and 71.1 on the west shore. The ratio of fish on the east shore to fish on the west shore was 282.8/71.1 or 3.98 to 1. The same process was repeated for each month. The average of the ratios for the several months represents an estimate of the relative abundance of the longjaw on the two sides of the southern part of the lake. Unweighted sums and averages were used to reduce the effects of unequal fishing effort in the different sections.

It is estimated that the longjaw was approximately 4⅓ (4.30) times as abundant in 1930 and 1931 on the east shore as along the west shore of southern Lake Michigan. Similarly, it was computed that the longjaw was about 1⅓ (1.32) times as abundant on the east shore in 1930 and 1931 as in northern Lake Michigan in 1932, and that in 1932 the abundance in the northern waters was about 4 (4.07) times that along the west shore in 1930 and 1931.

The above estimates ignored the length of time the nets fished between lifts in each section of the lake. On the average the nets fished 11.6 nights on both the east and west shores of southern Lake Michigan in 1930 and 1931. The somewhat more restricted data used to compute the relative abundance in northern Lake Michigan as compared with that in the southern section were based on specimens taken from nets that fished an average of 5.8 days between lifts in northern Lake Michigan, 11.1 days off the east shore, and 11.7 days along the west shore.

It is apparent that the length of time between lifts in 1930 and 1931 could have had no effect on the estimate of relative abundance of the longjaw off the two shores of the southern region. The shorter fishing time of the nets in northern waters makes it appear probable that the estimated relative abundance of the population in that area is too low. Data published by Van Oosten (1935) and unpublished records on file in the Great Lakes Laboratory, U. S. Fish and Wildlife Service, suggest that the catch would have increased by as much as 25 percent had the nets in northern Lake Michigan fished 11 or 12 days instead of 6. If the estimates of relative abundance are adjusted by increasing the average number of fish in the northern region by 25 percent, the abundance of the longjaw along the east shore in 1930 and 1931 would be about equal (1.06 instead of 1.32) to that in northern Lake Michigan in 1932, and the abundance in the northern section in 1932 would be about 5 times (5.1 instead of 4.07) that along the west shore in 1930 and 1931. These adjusted estimates of the relative abundance represent at best a possible improvement over the computations made without regard for fishing time, but do not necessarily give strictly accurate figures on the relative abundance of the longjaw in the different sections of the lake.

The influence of ecological factors on the distribution and relative abundance of the longjaw in the different sections of the lake cannot be determined because of the lack of complete data. The temperature of the water did not show any close relationship with the abundance of the species. The temperature near the bottom at all depths in which *L. alpenae* was most concentrated ranged from 3.8° C. to 7.0° C. (38.8° to 44.6° F.). The extreme temperatures in which the longjaw was found were 1.5° C. and 11.2° C. (34.7° and 52.2° F.).

Factors other than the ecological may have been of much greater importance in determining the relative abundance of the species, particularly along the two shores of the southern part of the lake. It may be seen in Table 1 that the longjaw was relatively scarce at depths of 70 fathoms and more. This fact strongly suggests that there is little, if any, intermingling of the bulk of the fish from the two sides of southern Lake Michigan and that each side has its own population of longjaws. It is common knowledge that the chub populations (several species) along the west shore (Illinois and Wisconsin waters) have been subjected to a more intensive fishery with smaller-meshed gill nets for a longer time than the populations along the east shore and the northern part of the lake (Michigan waters). The relative scarcity of the longjaw off the west shore was, therefore, associated with a greater fishing intensity which it seems reasonable to conclude must have been a factor in the abundance of the fish in these waters.

The conclusion that there are separate populations of the longjaw along the two shores of the lower lake is strengthened by the fact that the related kiyi (*L. kiyi*), which inhabits depths of 50 fathoms and more, was found by Hile and Deason (1947) to be nearly uniformly distributed throughout the central basins of the southern region where the water was of sufficient depth, whereas the longjaw was scarce at the greater depths. The larger size of the longjaws taken from northern Lake Michigan suggests that they also form a separate population.

AGE COMPOSITION AND LENGTH FREQUENCIES

The length-frequency distribution of the longjaws of northern Lake Michigan are given in Table 2 for each age group. Despite the fact that these fish were collected from three localities and on three widely separate dates in 1923 (Ile aux Galets, June 15; Northport, July 31; and Charlevoix, August 21), the frequency data for the separate collections were so similar that they could be combined. The lengths at capture showed no progressive increase as the season advanced (perhaps because of the selective action of the gill nets). Also, the frequency data for the sexes were so similar that they too could be combined. The number of specimens in each age group, their average standard and total lengths, and the percentage of each group in the total number are given at the bottom of the table. The youngest fish taken in 1923 were in age-group II and the oldest in age-group IX. Age-group IV dominated the samples (53.8 percent of the total). Age-group III was represented by 20.9 percent, and age-group V, the third most abundant group, by 10.6 percent of the total. The order of abundance of the other age groups from greatest to least was: VI, II, VII, VIII, and IX with none contributing greatly to the total sample.

TABLE 2.—*Length-frequency distribution of the longjaw in northeastern Lake Michigan in 1923 according to age*

[The sexes are combined]

Standard length interval (millimeters)	Total length[1] (inches)	Age group								Total
		II	III	IV	V	VI	VII	VIII	IX	
200–209...	9.6	1	–	2	–	–	–	–	–	3
210–219...	10.1	1	2	–	–	–	–	–	–	3
220–229...	10.6	2	4	2	–	–	–	–	–	8
230–239...	11.0	6	18	19	–	–	–	–	–	43
240–249...	11.4	2	17	35	1	–	–	–	–	55
250–259...	11.9	–	11	38	6	–	–	–	–	55
260–269...	12.4	1	11	39	10	–	–	–	–	61
270–279...	12.8	–	2	23	5	4	–	–	–	34
280–289...	13.3	–	2	9	5	4	1	–	–	21
290–299...	13.8	–	–	1	5	5	3	–	–	14
300–309...	14.3	–	–	3	2	1	–	–	–	6
310–319...	14.7	–	–	1	–	2	–	–	–	3
320–329...	15.2	–	–	–	–	3	3	–	–	6
330–339...	15.5	–	–	–	–	–	1	1	–	2
340–349...	16.0	–	–	–	–	–	–	–	–	–
350–359...	16.5	–	–	–	–	–	–	1	–	1
360–369...	16.9	–	–	–	–	–	–	1	–	1
370–379...	17.4	–	–	–	–	–	1	–	1	2
380–389...	17.9	–	–	–	–	1	–	1	–	2
Number.............		13	67	172	34	20	9	4	1	320
Average standard length		233	247	257	274	300	317	357	372	262
Average total length...		10.9	11.6	12.0	12.8	14.0	14.8	16.6	17.3	12.2
Percentage of total....		4.1	20.9	53.8	10.6	6.3	2.8	1.2	0.3	100.0

[1] Equivalent to midpoints of intervals of standard length

Length distribution according to age, average lengths, and the age composition are shown in Table 3 for the longjaws taken on November 10, 1928, off Grand Haven, Michigan, in southern Lake Michigan. The absence of pronounced differences between the sexes and between fish taken by the 2½- and 2¾-inch-mesh gill nets made it possible to combine all of the data. The youngest fish taken in 1928 were in age-group II and the oldest in age-group V. Age-group III made up 55.2 percent of the total. Age-group IV was the next most abundant group with 31.0

TABLE 3.—*Length-frequency distribution of the longjaw in southern Lake Michigan in 1928 according to age*

[The sexes are combined]

Standard length interval (millimeters)	Total length[1] (inches)	Age group				Total
		II	III	IV	V	
210–219 . . .	10.1	1	–	–	–	1
220–229 . . .	10.6	3	2	–	–	5
230–239 . . .	11.0	1	10	4	–	15
240–249 . . .	11.4	1	10	3	–	14
250–259 . . .	11.9	1	9	8	1	19
260–269 . . .	12.4	–	1	2	–	3
270–279 . . .	12.8	–	–	1	–	1
Number		7	32	18	1	58
Average standard length		232	243	251	259	244
Average total length . .		10.9	11.4	11.7	12.1	11.4
Percentage of total. . . .		12.1	55.2	31.0	1.7	100.0

[1] Equivalent to midpoints of intervals of standard length

percent, and the II group ranked third with 12.1 percent. Age-group V was represented by only one fish (1.7 percent of the total sample).

A comparison of Tables 2 and 3 reveals that not only was the average total length of all fish in the 1928 sample (11.4 inches) less than that in 1923 (12.2 inches) but also that the individuals taken in 1928 averaged younger than those captured in 1923. The order of abundance of the three best represented age groups, from strongest to weakest, was IV, III, and V in 1923, and III, IV, and II in 1928. No fish older than V was taken in 1928, whereas in 1923 age-group VI was represented by more individuals than was the II group. Although the conclusions to be drawn from a comparison of Tables 2 and 3 are weakened considerably because of the small number of specimens in the 1928 sample, the data nevertheless indicate strongly that the longjaws entered the fishery at an earlier age in southern Lake Michigan than in the northeastern part of the lake.

As was to be expected the length distributions and the averages of the age groups in the samples of both years show a progressive increase in length with each increase in age. The modal length, however, did not always change with increase of age (compare, for example, age-groups II and III and IV and V of the 1923 collection). There was extensive overlapping of the lengths of fish in the different age groups in both 1923 and 1928. Several of the 10-millimeter intervals of standard length contained representatives of as many as four age groups, and one (280–289) in 1923 contained fish of five ages.

Many more length-frequency data for longjaws are shown in Table 4 than in Tables 2 and 3. A comparison of the 1923 frequencies of all fish combined with those of longjaws taken in 2¾-inch-mesh gill nets in 1932 from northern Lake Michigan (Table 4) reveals a marked

TABLE 4.—*Length-frequency distribution of the longjaw in Lake Michigan according to size of mesh in the gill nets and section of the lake*

[The total lengths were computed to be equivalent to the midpoints of the standard-length intervals. The sexes are combined]

Standard length interval (millimeters)	Total length[1] (inches)	Southern Lake Michigan, 1930–1931							Northern Lake Michigan, 1932			
		2⅜	2½	2⅝	2¾	3	Total	2½–2¾	2½	2⅝	2¾	Total
130–139 . . .	6.3	–	–	–	–	1	1	–	–	–	–	–
140–149 . . .	6.8	–	1	1	–	–	2	2	–	–	–	–
150–159 . . .	7.3	2	–	3	–	1	6	3	–	–	–	–
160–169 . . .	7.8	2	3	3	1	–	9	7	–	–	–	–
170–179 . . .	8.2	–	1	3	–	2	6	4	–	–	–	–
180–189 . . .	8.7	8	4	5	–	2	19	9	–	–	–	–
190–199 . . .	9.2	62	14	4	4	4	88	22	1	1	–	2
200–209 . . .	9.6	136	24	10	11	7	188	45	1	1	1	3
210–219 . . .	10.1	289	55	28	6	7	385	89	13	1	2	16
220–229 . . .	10.6	341	126	62	13	11	553	201	67	17	9	93
230–239 . . .	11.0	288	167	69	27	7	558	263	147	43	15	205
240–249 . . .	11.4	158	130	100	40	7	435	270	291	142	38	471
250–259 . . .	11.9	86	108	81	61	6	342	250	382	262	102	746
260–269 . . .	12.4	37	57	41	43	8	186	141	327	293	211	831
270–279 . . .	12.8	9	30	25	26	10	100	81	188	290	244	722
280–289 . . .	13.3	2	6	5	8	6	27	19	84	169	186	439
290–299 . . .	13.8	6	2	3	4	8	23	9	53	73	79	205
300–309 . . .	14.3	–	2	3	3	2	10	8	24	42	70	136
310–319 . . .	14.7	1	–	–	1	2	4	1	13	25	23	61
320–329 . . .	15.2	–	–	–	2	1	3	2	5	12	23	40
330–339 . . .	15.5	–	–	–	–	–	–	–	–	8	7	15
340–349 . . .	16.0	–	–	–	–	1	1	–	–	6	8	14
350–359 . . .	16.5	–	–	–	–	–	–	–	1	–	3	4
360–369 . . .	16.9	–	–	–	–	–	–	–	–	–	–	–
370–379 . . .	17.4	–	–	–	–	2	2	–	–	2	–	2
460–469 . . .	21.6	–	–	–	–	–	–	–	–	–	1	1
Total number		1,427	730	446	250	95	2,948	1,426	1,597	1,387	1,022	4,006
Number measured		980	594	381	240	95	2,290	1,215	1,441	1,242	968	3,651
Average standard length		225	237	240	251	249	235	241	258	268	277	266
Average total length . .		10.6	11.1	11.2	11.7	11.7	11.0	11.3	12.1	12.5	13.0	12.5

[1] Equivalent to midpoints of intervals of standard length

similarity between the two series in spite of the long time interval between the dates of collection. The 1932 fish were somewhat longer; the bulk of them ranged between 11.0 and 15.2 inches as compared with a corresponding range of 11.0–13.8 inches for the 1923 specimens; the average length of the former was 13.0 inches, of the latter 12.2 inches; their modal lengths were 12.8 and 12.4 inches respectively. The 1928 collection was so small that it warrants no detailed discussion here.

The length distributions and average sizes of the longjaws taken in 1930 and 1931 from both shores of southern Lake Michigan were so similar that the data for the two years and the two areas have been combined. Table 4 shows the length frequencies of the fish caught by the experimental gill nets for each size of mesh separately and for the northern and southern parts of the lake. The numbers of fish in each length interval do not represent specimens actually measured (compare third and fourth lines from the bottom of Table 4) but were estimated by multiplying the number measured by the ratio of the total number of chubs in the net to the number in the sample measured. This procedure seems desirable, since it eliminates the effects of variation in the percentage of the total used in the sample (for example: when the catch was large enough to make it impossible to measure all fish, the sample taken from the 2⅜-inch-mesh nets was always a smaller percentage of the total than was the sample from nets with larger sizes of mesh). The numbers taken by the 2½-, 2⅝-, and 2¾-inch-mesh nets in southern Lake Michigan during 1930 and 1931 were combined for each length interval to permit direct comparison with the data obtained in 1932 from the northern part of the lake.

The range in length of the longjaws varied but little among the four smaller sizes of mesh employed in the gill nets. However, the modal as well as the average length increased progressively as the size of mesh was increased by one-eighth-inch steps from 2⅜ to 2¾ inches (the modal from 10.6 to 11.9 and the average from 10.6 to 11.7 inches in 1930–1931, and correspondingly from 11.9 to 12.8 and from 12.1 to 13.0 inches in 1932). The length distribution of the longjaws taken by the 3-inch-mesh nets in 1930–1931 tended to be bimodal with the greatest number (11 fish) in the 220 to 229-millimeter interval of standard length (10.6 inches, total length) and the second mode (10 fish) in the 270 to 279-millimeter interval (12.8 inches, total length). The mode at 220–229 millimeters probably represents fish that were captured accidentally (entangled in the meshes by mouth parts) whereas the mode at 270–279 millimeters no doubt represents the fish actually gilled in that size of mesh.

The relative abundance of the longjaws taken by each size of mesh changed as the fish length increased. In southern Lake Michigan longjaws with total lengths of less than 11.9 inches were taken in greatest numbers by the 2⅜-inch-mesh nets, and the number in each of these shorter length intervals in general decreased as the size of mesh increased.

The relative abundance of the fish taken by each of the larger sizes of mesh (except the 3-inch nets) became progressively greater as their length increased above 11.9. The 3-inch-mesh nets apparently were too large to take large numbers of longjaws of any size reached in the southern part of the lake. The longjaws in the northern area with total lengths of less than 12.8 inches were taken in largest numbers by the 2½-inch-mesh nets. As the fish length increased beyond 12.8 inches, the larger meshes progressively took more fish than the smaller meshes. The shifting in the relative number of longjaws taken by each size of mesh as the lengths increased no doubt is the result of the selective action of the gill nets.

The greatest effect of the size of mesh on the capture of longjaws was in the numbers taken. The 2½-inch-mesh nets took 51 percent of the number caught in the 2⅜-inch-mesh nets, the 2⅝-inch-mesh nets took 31 percent, the 2¾-inch-mesh nets captured 18 percent, and the 3-inch-mesh nets caught only 7 percent in southern Lake Michigan in 1930–1931. Similarly in the northern part of the lake in 1932, with each increase in the size of mesh from 2½ to 2⅝ to 2¾ inches, the resultant catch in the larger meshes equaled 87 and 64 percent respectively of that taken in the smallest mesh. The greater reduction in the number taken with each increase in size of mesh in 1930 and 1931 no doubt was due to the smaller size of the fish taken from the southern waters.

It is apparent from Table 4 that the longjaws captured in 1930 and 1931 in southern Lake Michigan were much shorter than those taken from northern Lake Michigan in 1932. The differences of 1.0 to 1.3 inches (mean, 1.2) in average total length of fish caught by the same size of mesh seem too great to be explained as due to different years of sampling. A comparison of the data of the 1928 sample from southern Lake Michigan (Table 6) with those of the 1923 fish from the northern region (Table 5) shows that not only did the fish from the south average younger than the specimens secured from the northern part of the lake, but also that their annual increment in length was less each year following the second. Although the 1928 sample was small, these data nevertheless suggest that the smaller average size of the individuals taken in southern Lake Michigan in 1930 and 1931 may have been due in part to the presence of a greater number of younger fish and to slower growth. It is also apparent that fish over 12.4 inches were relatively scarce in the southern but abundant in northern waters. This fact can in all probability be ascribed to a difference in fishing intensity. It is common knowledge that the chub fisheries were prosecuted with greater vigor south of the Frankfort-Kewaunee line than north of it.

The shortest longjaw examined was a mature male that measured 136 millimeters, standard length (6.4 inches, total length); it was taken off Two Rivers, Wisconsin, on July 21, 1930. The same lift also produced the shortest female, which likewise was sexually mature; it measured 149 millimeters, standard length (7.0 inches, total length). The weights of these two fish were not recorded. The lightest male weighed 35 grams and measured 146 millimeters, standard length (1.25 ounces and 6.9 inches, total length). The lightest female weighed 50 grams and measured 151 millimeters, standard length (1.75 ounces and 7.1 inches, total length). Both of these fish were sexually mature and taken off Racine, Wisconsin, on November 13, 1930. By far the largest longjaw encountered was a female taken off Manistique, Michigan, on September 1, 1932, which measured 464 millimeters, standard length, and weighed 1,857 grams (21.5 inches, total length, and 4 pounds, 1½ ounces). The longest and also the heaviest male was captured off Ludington, Michigan, on August 13, 1930; it measured 373 millimeters and weighed 737 grams (17.3 inches, total length, and 1 pound, 10 ounces).

GROWTH IN LENGTH AND WEIGHT

The data on length at capture and the calculated length at the end of each year of life are presented in Table 5 for the 1923 samples with the localities and sexes combined and in Table 6 for the 1928 collection with the sexes combined. Grand averages are shown at the bottom of the tables. Weights were not obtained for the fish taken in 1923 whose ages were determined because of the generally unsatisfactory nature of such data taken from preserved specimens. Differences in the growth of the sexes and of fish taken at the different localities in 1923 were not large enough to warrant detailed presentation. The data on length at capture in Table 5 are the averages of fish taken during June, July, and August, and do not represent the size attained at the end of a year of life, but the lengths at capture in Table 6 are the averages of fish taken on November 10 when the growth for the year may be assumed to have been completed.

In the 1923 fish (Table 5) the calculated lengths at the end of each year of life decreased with each successive increase of age of the fish upon which the calculations were based from age-group II to VII (Lee's phenomenon) with the single exception of age-group VI whose lengths were slightly larger than those for the V group. The few individuals in age-groups VIII and IX were large at the end of all years of life. Similarly Lee's phenomenon was also present in the calculated lengths of the well represented age groups taken in 1928 (Table 6).

The grand average calculated lengths at the end of each year of life are plotted in Figure 2 for both the 1923 and 1928 samples of longjaws. Growth was rapid during the first year of life (5.3–5.8 inches). The length increment added during the second year was approximately half that of the first year. The growth during the third and fourth years (also the fifth in 1928) continued to decrease but at a much slower rate. The annual increments in length of the 1923 fish during the fourth through the eighth year of life remained at the same level (1.1–1.4 inches). The ninth-year increment was based on only one fish. Although the 1928 fish from southern Lake Michigan grew faster than the 1923

TABLE 5.—*Average length at capture of the longjaws collected in Lake Michigan in 1923, and the average calculated lengths and increments attained by the age groups at the end of each year of life*

[The sexes are combined]

Age group	Number of fish	Standard length (millimeters)	Total length (inches)	Calculated standard length (millimeters) at end of year								
				1	2	3	4	5	6	7	8	9
II. .	13	233	10.9	127	188	–	–	–	–	–	–	–
III. .	67	247	11.6	118	175	218	–	–	–	–	–	–
IV. .	172	257	12.0	111	168	208	238	–	–	–	–	–
V. .	34	274	12.8	109	163	202	234	258	–	–	–	–
VI. .	20	300	14.0	113	165	203	237	265	285	–	–	–
VII. .	9	317	14.8	108	162	200	230	261	287	304	–	–
VIII. .	4	357	16.6	125	185	227	254	288	312	331	346	–
IX.	1	372	17.3	119	172	211	239	264	293	316	339	360
II–IX. .	320	–	–	113	169	209	238	262	289	312	344	360
Annual increment in length				113	56	40	29	24	27	23	32	16
Average total length (inches)				5.3	8.0	9.9	11.1	12.3	13.5	14.6	16.0	16.7
Annual increment (inches)				5.3	2.7	1.9	1.2	1.2	1.2	1.1	1.4	0.7

TABLE 6.—*Average length and weight at capture of the longjaws collected in Lake Michigan in 1928, and the average calculated lengths and increments attained by the age groups at the end of each year of life*

[The sexes are combined]

Age group	Number of fish	Standard length (millimeters)	Total length (inches)	Weight (grams)	Weight (ounces)	Calculated standard length (millimeters) at end of year				
						1	2	3	4	5
II . .	7	232	10.9	165	5.8	136	200	–	–	–
III . .	32	243	11.4	204	7.2	124	180	219	–	–
IV . .	18	251	11.7	225	7.9	115	170	209	236	–
V . .	1	259	12.1	280	9.9	122	159	189	218	245
II–V . .	58	–	–	–	–	123	179	215	235	245
Annual increment in length						123	56	36	20	10
Average total length (inches)						5.8	8.4	10.1	11.0	11.5
Annual increment (inches)						5.8	2.6	1.7	0.9	0.5

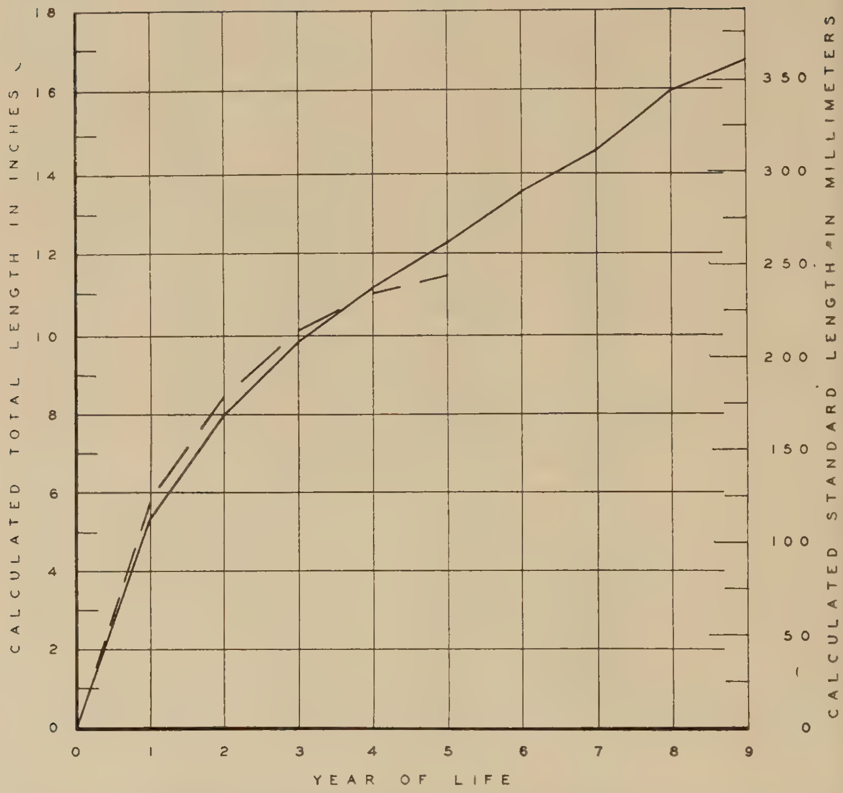

FIGURE 2.—Calculated growth in length of the longjaw in Lake Michigan. The sexes are combined. Solid line = 1923; broken line = 1928.

specimens from the northern region in the first year, their increments were less in each later year.

Since actual weights were not obtained for the 1923 longjaws nor available for age-groups O and I in 1928, calculated values were employed for the study of growth in weight (Table 7 and Fig. 3). These values were computed by use of the formula derived from the length-weight data secured in 1930–1932 (Table 10). The empirical weights of the fish caught in November 1928 were somewhat greater than those computed (Table 7). Such discrepancies were to be expected, since many of the 1928 individuals were in spawning condition and consequently heavier than the specimens of corresponding lengths caught in 1930–1932 at times other than the spawning season.

The data of Table 7 and Figure 3 reveal that the longjaw in both the 1923 and 1928 collections added but little weight during the first year

TABLE 7.—*Weights in grams and ounces computed to correspond with the calculated standard length at the end of each year of life, and the annual increments of growth in weight of the longjaws taken from northeastern Lake Michigan in 1923 and from southern Lake Michigan in 1928*

[The sexes are combined. See section on length-weight relationship for the equation employed]

Year of life	1923				1928					
	Weight (grams)	Increment (grams)	Weight (ounces)	Increment (ounces)	Weight (grams)	Increment (grams)	Weight (ounces)	Increment (ounces)	Actual weights (ounces)	
									Weight	Increment
1	19	19	0.7	0.7	23	23	0.8	0.8	–	–
2	63	44	2.2	1.5	76	53	2.7	1.9	–	–
3	121	58	4.3	2.1	131	55	4.6	1.9	5.8	–
4	181	60	6.4	2.1	174	43	6.1	1.5	7.2	1.4
5	243	62	8.6	2.2	198	24	7.0	0.9	7.9	0.7
6	328	85	11.6	3.0	–	–	–	–	9.9	2.0
7	414	86	14.6	3.0	–	–	–	–	–	–
8	558	144	19.7	5.1	–	–	–	–	–	–
9	642	84	22.6	2.9	–	–	–	–	–	–

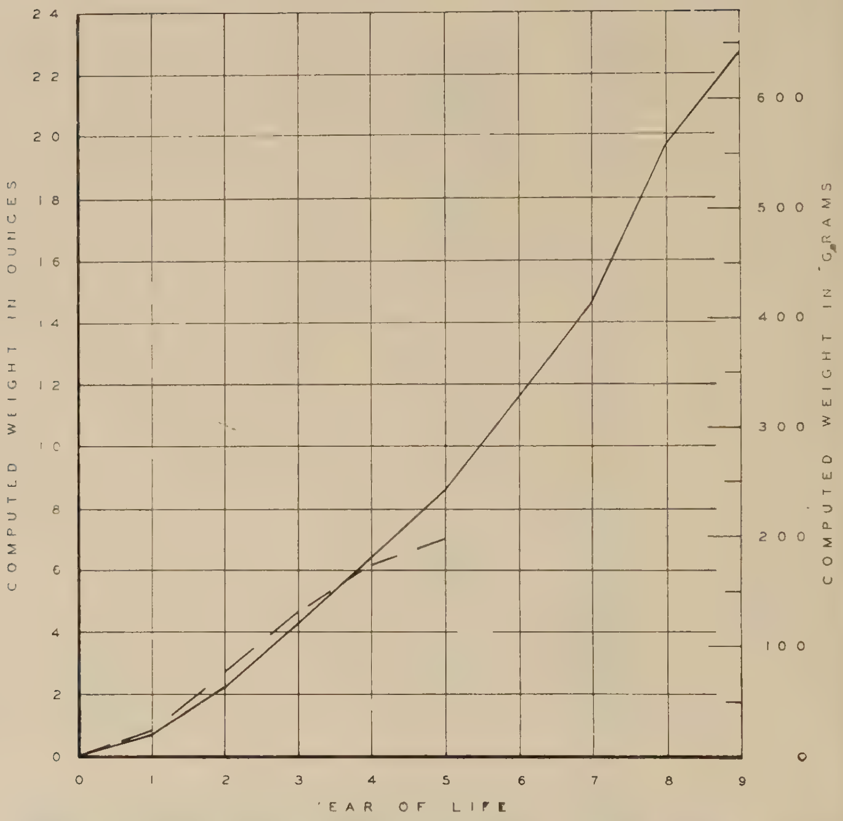

FIGURE 3.—Computed growth in weight of the longjaw in Lake Michigan. The sexes are combined. Solid line = 1923; broken line = 1928.

(0.7 and 0.8 ounce). Thereafter the annual increments of the well represented age groups varied from 1.5 to 3.0 ounces in the 1923 fish and from 1.5 to 1.9 ounces in the 1928 specimens. In the former the increments tended to increase with the age of the fish. There was rather close agreement between the average weights of the fish of the two collections. At the end of four years of growth the 1923 fish had reached a weight of 6.4 ounces (11.1 inches, total length) and the 1928 specimens had attained a weight of 6.1 ounces (11.0 inches).

It should be pointed out that the data on growth, both in length and weight, may have been affected to an unknown degree by the selective action of gill nets. Usually commercial gill nets take only the larger individuals of the younger year classes and the smaller fish of the older

TABLE 8.—*Growth compensation in the four best represented age groups of the longjaw in Lake Michigan in 1923 and 1928*

[As demonstrated by the computed standard lengths and average increments of length for each year of life of three first-year size groups. The sexes are combined]

Age group and year	Interval of first-year length in millimeters	Number of fish	Average computed standard length in millimeters for year					Average standard length at capture	Average computed increment of length in year[1]					
			1	2	3	4	5		1	2	3	4	5	6
III (1923)	Less than 110	18	100	162	207	–	–	240	100	62	45	33	–	–
	110 to 124	25	116	177	218	–	–	246	116	61	41	28	–	–
	125 and more	24	132	182	225	–	–	252	132	50	43	27	–	–
	Maximum difference		32	20	18	–	–	12	–	–	–	–	–	–
IV (1923)	Less than 105	44	96	159	201	233	–	252	96	63	42	32	19	–
	105 to 114	59	110	166	208	239	–	258	110	56	42	31	19	–
	115 and more	69	123	174	213	242	–	259	123	51	39	29	17	–
	Maximum difference		27	15	12	9	–	7	–	–	–	–	–	–
V (1923)	Less than 105	11	94	155	198	232	258	273	94	61	43	34	26	15
	105 to 114	10	110	161	200	232	257	272	110	51	39	32	25	15
	115 and more	13	122	171	208	238	259	276	122	49	37	30	21	17
	Maximum difference		28	16	10	6	2	4	–	–	–	–	–	–
III (1928)	Less than 115	10	106	166	209	–	–	236	106	60	43	27	–	–
	115 to 130	11	125	179	218	–	–	241	125	54	39	23	–	–
	131 and more	11	140	192	228	–	–	249	140	52	36	21	–	–
	Maximum difference		34	26	19	–	–	13	–	–	–	–	–	–

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[1] The final increment is the growth to time of capture and represents an uncompleted season except for age-group III of 1928

TABLE 9.—*Length increments (millimeters) added by the Lake Michigan langjaws of each age during the full season of 1922 and to three dates in 1923*

[At the bottom are the percentages of 1922 growth completed at each date in 1923. Numbers of specimens in parentheses]

Item	Year of life							Weighted average, all fish	Weighted average, years of life 5–9
	3	4	5	6	7	8	9		
Growth (millimeters), full season, 1922	43 (67)	30 (172)	24 (34)	20 (20)	17 (9)	15 (4)	21 (1)	–	–
Growth (millimeters) in 1923 to:									
June 15	–	31 (5)	14 (31)	14 (6)	13 (2)	12 (2)	–	–	–
July 31	42 (6)	30 (32)	18 (75)	17 (20)	16 (12)	13 (6)	10 (2)	–	–
August 21	47 (7)	29 (30)	21 (66)	15 (8)	14 (6)	9 (1)	13 (2)	–	–
Percentage of 1922 growth completed in 1923 to:									
June 15	–	103	58	70	76	80	–	66	62
July 31	98	100	75	85	94	87	48	84	79
August 21	109	97	88	75	82	60	62	90	85

age groups. It is believed, however, that except for the last years of life the grand average calculated lengths and weights of the longjaw approximate the true values for the population in the lake, since they were based on a group of different year classes which included both fast- and slow-growing individuals.

GROWTH COMPENSATION

Growth compensation, or the tendency for the smaller young fish to grow more rapidly in the later years of life than the larger young, is a common phenomenon among fishes. Growth compensation among the chubs has been demonstrated for the Lake Superior longjaw (*L. zenithicus*—not the longjaw of Lake Michigan) by Van Oosten (1937), for Reighard's chub (*L. reighardi*) in Lake Michigan by Jobes (1943), for the kiyi (*L. kiyi*) of Lake Michigan by Deason and Hile (1947), and for the bloater (*L. hoyi*) of Lake Michigan by Jobes (1949).

Four age groups (III, IV, and V in 1923 and III in 1928) contained enough specimens to permit an analysis of growth compensation in the longjaw of Lake Michigan. It may be seen from Table 8 that in each age group the smallest yearlings showed the best growth and the largest yearlings the poorest. It is evident then that growth compensation did occur, although not to such an extent as to eliminate completely the discrepancies in size at the end of any year of life or at the time of capture.

GROWTH DURING THE SEASON

Because the longjaws collected in 1923 were taken on three separate dates (June 15, July 31, and August 21), it is possible to estimate the progress of their growth during the season by computing the percentage of the growth completed in 1923 in the total growth attained in 1922 for corresponding years of life. The pertinent data are given in Table 9. Since the youngest fish were in their third year of life (Table 2), nothing can be learned of the course of growth during either of the first two years.

The percentages indicate that the II- and III-group fish had practically completed the season's growth by the middle of June and the end of July whereas the older longjaws had not completed this growth by August 21. It is hardly probable that the young fish actually had completed their growth so early in the season. Then too the percentages did not always show a consistent increase with the advance of the season, although in the older fish the July values were always higher than those for June. Some of the apparent discrepancies may be attributed to the paucity of specimens; others may have been due to differences in growth rates in 1922 and 1923 for corresponding years of life, to Lee's phenomenon, to gill-net selectivity, and other factors. Because of these various disturbing elements, it seems highly desirable to employ weighted averages of the percentages to obtain a better approximation of the progress of seasonal growth in 1923. Two averages are given—one for all fish and the other including only fish of 5–9 years of age. These two averages show the same trend, although the percentage growth completed is slightly less (4–5 percent) for all three dates when the young fish are excluded.

The data suggest that the longjaws taken on June 15, 1923, had completed about 62–66 percent of the growth attained during the entire season of 1922. By July 31 about 79–84 percent of the growth had been completed and by August 21 about 85–90 percent had been attained. It is apparent that the major part of the seasonal growth was completed by the longjaws by the middle of June and that the rate of growth thereafter was relatively slow.

LENGTH-WEIGHT RELATIONSHIP AND CONDITION

Data on the relationship between the length and weight of the longjaw in Lake Michigan in 1930–1932 are presented in Table 10 and Figure 4. Although there were certain differences in the length-weight relationship that seemed to be associated with the mesh size of the nets, sex, locality, season, and year of capture, the differences were so small that it is believed justifiable to combine all data to obtain a single length-weight curve. Also, the deviations of the empirical data from a simple parabolic curve were present when the data were broken down into smaller units. Figure 4 shows that the major deviations of the empirical data from the curve were at standard lengths of 190–225, 250–300, and 340 and more millimeters. The deviations from the parabolic curve for all specimens seemed to result from the empirical data falling along three separate curves. Equations of the type $W = cL^n$ were fitted separately to the data on length and weight for longjaws with standard lengths of 145–189, 190–284, and 285–378 millimeters. The resulting curves agreed with the empirical data almost perfectly. However, the tremendous difficulties of employing three equations for calculating the weights of longjaws of various lengths makes such a procedure impractical. It is believed, therefore, that an equation derived from all of the data affords the best description of the length weight relationship of the longjaw in Lake Michigan. Although the use of a single equation for computing weights for all lengths of fish results in some fairly large discrepancies with the empirical weights (Table 10), it cannot be said that the discrepancies are errors because of the heterogeneous nature of the basic data. The equation believed best suited to computing weights for the longjaw in Lake Michigan is $W = 0.96288 \times 10^{-5} L^{3.06060}$, in which W = weight in grams and L = standard length in millimeters.

Figure 4, based on the data of Table 10, has been prepared to permit ready conversion between the metric and English systems of measurement. The factors for converting standard to total length, and vice versa, are given in Table 11. One ounce equals 28.35 grams.

Despite the fact that the weight of a fish seldom increases exactly as the cube of the length, the coefficient of condition (K) nevertheless serves

TABLE 10.—*Length-weight relationship of the longjaw in Lake Michigan, 1930–1932*

[The data for the sexes from all localities are combined. The computed weights were obtained from the equation $W=0.96288 \times 10^{-5} L^{3.0606}$]

Standard length interval (millimeters)	Total length[1] (inches)	Empirical weight		Computed weight (grams)	K	Number of fish
		Ounces	Grams			
145–149...	6.9	1.25	35	41	1.12	1
150–154...	7.2	1.75	50	45	1.45	1
155–159...	7.4	1.75	50	51	1.29	2
160–164...	7.6	1.80	51	57	1.18	1
165–169...	7.9	2.00	57	63	1.18	2
170–174...	8.1	–	–	67	–	–
175–179...	8.3	2.42	69	72	1.27	3
180–184...	8.6	2.88	82	80	1.36	4
185–189...	8.8	3.17	90	86	1.38	10
190–194...	9.1	3.68	104	94	1.47	21
195–199...	9.3	3.88	110	101	1.44	38
200–204...	9.5	4.18	119	109	1.44	49
205–209...	9.8	4.59	130	118	1.47	75
210–214...	10.0	4.74	134	127	1.41	130
215–219...	10.2	5.17	147	136	1.44	134
220–224...	10.5	5.49	156	146	1.43	192
225–229...	10.7	5.68	161	156	1.38	214
230–234...	10.9	6.02	171	167	1.37	238
235–239...	11.1	6.34	180	179	1.35	269
240–244...	11.3	6.64	188	190	1.33	347
245–249...	11.6	6.95	197	203	1.31	338
250–254...	11.8	7.26	206	215	1.29	420
255–259...	12.0	7.67	217	229	1.28	421
260–264...	12.3	8.02	227	243	1.26	477
265–269...	12.5	8.45	240	257	1.26	356
270–274...	12.7	8.91	253	272	1.26	402
275–279...	13.0	9.50	269	288	1.27	299
280–284...	13.2	9.81	278	304	1.24	246
285–289...	13.4	10.60	301	321	1.30	166
290–294...	13.7	11.38	323	338	1.30	123
295–299...	13.9	11.92	338	356	1.29	79
300–304...	14.1	12.78	362	375	1.31	70
305–309...	14.4	13.70	388	394	1.34	55
310–314...	14.6	14.72	418	414	1.38	32
315–319...	14.8	14.71	417	435	1.31	26
320–324...	15.1	15.86	450	452	1.36	27
325–329...	15.3	17.58	498	478	1.42	13
330–334...	15.4	17.12	485	501	1.33	7
335–339...	15.6	18.09	513	524	1.34	6
340–344...	15.9	21.10	598	549	1.49	5
345–349...	16.1	21.39	606	573	1.45	7
350–354...	16.3	21.50	610	610	1.38	1
355–359...	16.6	23.75	673	620	1.49	3
360–364...	16.8	–	–	653	–	–
365–369...	17.0	–	–	681	–	–
370–374..	17.3	26.08	739	709	1.44	3
375–379...	17.5	29.50	836	745	1.55	1

[1] Equivalent to midpoints of intervals of standard length

as a fixed standard for comparing plumpness or body form. The coefficient of condition, as used in this paper, was determined by the formula, $K = \frac{W \times 10^5}{L^3}$, where W = weight in grams, and L = standard length in millimeters.

The condition of all fish collected in 1930–1932 was determined from

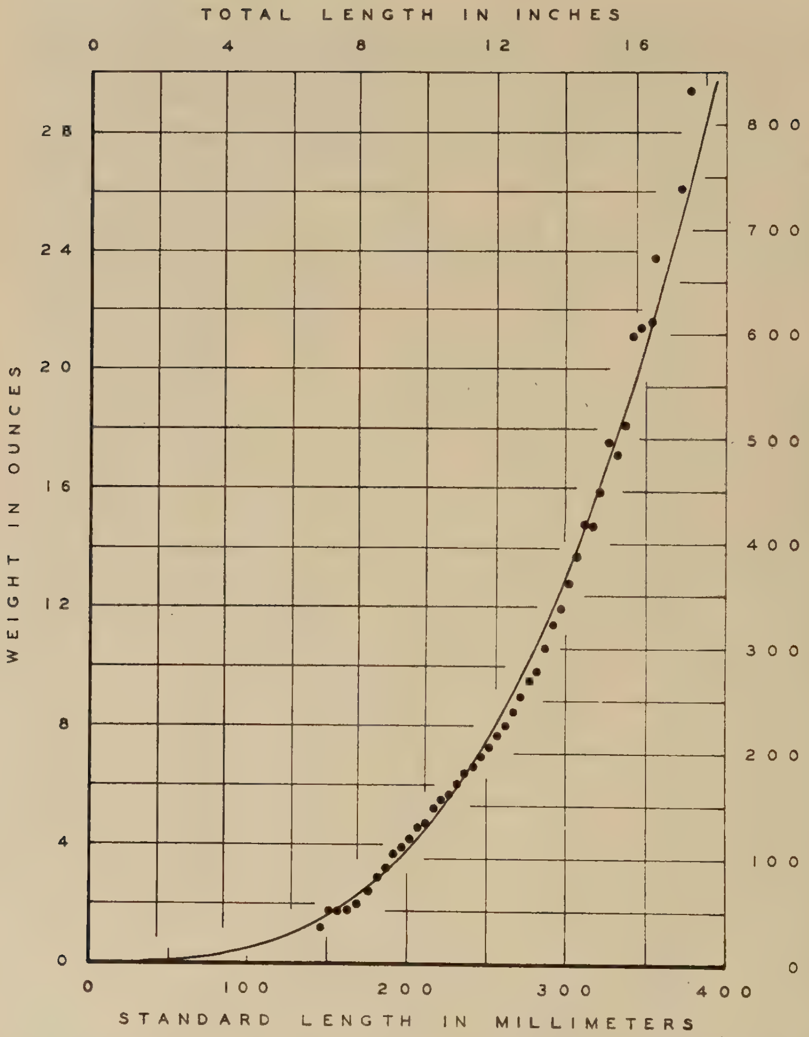

FIGURE 4.—Length-weight relationship of the longjaw in Lake Michigan. The sexes are combined. Smooth curve = computed relationship. Solid circles = empirical data.

the average length and weight for each 5-millimeter interval of standard length (Table 10). The value of the coefficient of condition (K) was low for the shorter fish but increased as the standard length increased to 194 millimeters. The values then tended to remain high for fish up to 225 millimeters standard length when they decreased progressively until

TABLE 11.—*Factors for conversions between standard length (S.L.) and total length (T.L.) for the longjaw in Lake Michigan with and without change of unit of measurement*

Standard length interval	Number of fish	S.L. to T.L.	T.L. to S.L.	S.L. (millimeters) to T.L. (inches)	T.L. (inches) to S.L. (millimeters)
140–229	1,028	1.1976	0.835	0.0472	21.209
230–329	5,105	1.1891	0.841	0.0468	21.361
330–469	38	1.1792	0.848	0.0464	21.539

the fish reached a length of 265 millimeters. Thereafter the coefficients fluctuated irregularly, but beginning with a standard length of 285 millimeters, they tended to increase again as the fish became longer. Some of the changes in the value of *K* at the different lengths may have been the result of the selective action of the nets whereby the more robust of the shorter and the more slender of the longer individuals are gilled and by the combination of the data from all sources (as shown below the *K* values were lower for fish in the northern than in the southern part of the lake). Since smaller longjaws (less than about 9 inches in length) were for the most part entangled in the meshes rather than gilled, their coefficients probably were affected but little by net selection. The high values of *K* for individuals between 9 and 10.5 inches and the low values for fish from about 12 to 13 inches may, however, have been the result, in part at least, of this selection.

The variations in the annual and monthly averages of *K* of longjaws are shown in Table 12 for the males and females separately and for all fish combined. The values for fish taken on the two shores of southern Lake Michigan in 1930 and 1931 were so similar that they have been combined. The individuals of both sexes taken in northern Lake Michigan in 1932 had lower values of *K* each month than the fish taken in southern Lake Michigan in 1930 and 1931, and values in 1931 usually were greater than those in 1930. The females were in slightly better condition than the males each month, except in June 1931 and September 1932, when the values of *K* were identical. The differences in relative heaviness between the sexes were so slight that the weighted average values of *K* for all males and all females were practically the same (1.30 for the males and 1.31 for the females).

It is apparent that individuals of both sexes were in the poorest condition in some month before August each year. The values of *K* for the males taken in 1931 were higher in May and June than in July. There was a sharp rise in the value of *K* in August after which it returned nearly to the May and June level only to rise again in November. In 1932 the value of *K* for the males was lowest in May, increased in June and July, remained at the July level in August, and increased in September. The coefficients of the females taken in 1931 changed but little from May

TABLE 12.—*Coefficient of condition of the longjaw in Lake Michigan according to sex and date of capture*

[Number of specimens in parentheses]

Sex	Year	April	May	June	July	August	September	October	November	Average
Male	1930	–	–	–	–	1.38 (171)	[1]1.39 (47)	–	1.32 (114)	1.36 (332)
	1931	–	1.36 (46)	1.36 (20)	1.30 (6)	1.45 (14)	1.38 (19)	1.37 (22)	1.42 (11)	1.38 (138)
	1932	–	[1]1.20 (33)	[2]1.24 (78)	1.26 (278)	1.26 (258)	1.31 (54)	–	–	1.26 (701)
	All	–	1.29 (79)	1.26 (98)	1.26 (284)	1.31 (443)	1.35 (120)	1.37 (22)	1.33 (125)	1.30 (1,171)
Female	1930	–	–	–	–	1.39 (518)	[1]1.43 (118)	–	1.38 (257)	1.39 (893)
	1931	–	1.37 (81)	1.36 (41)	1.41 (18)	1.46 (36)	1.45 (48)	1.43 (108)	1.46 (21)	1.41 (353)
	1932	[1]1.21 (7)	[1]1.24 (207)	[2]1.26 (371)	1.29 (1,087)	1.29 (1,048)	1.31 (177)	–	–	1.28 (2,897)
	All	[1]1.21 (7)	1.28 (288)	1.27 (412)	1.29 (1,105)	1.33 (1,602)	1.37 (343)	1.43 (108)	1,39 (278)	1.31 (4,143)
All fish	1930	–	–	–	–	1.39 (689)	[1]1.42 (165)	–	1.36 (371)	1.38 (1,225)
	1931	–	1.36 (127)	1.36 (61)	1.38 (24)	1.45 (50)	1.43 (67)	1.42 (130)	1.45 (32)	1.40 (491)
	1932	[1]1.21 (7)	[1]1.23 (240)	[2]1.25 (449)	1.28 (1,365)	1.28 (1,306)	1.31 (231)	–	–	1.27 (3,598)
	All	[1]1.21 (7)	[2]1.27 (367)	[2]1.26 (510)	1.28 (1,389)	1.32 (2,045)	1.37 (463)	1.42 (130)	1.37 (403)	1.31 (5,314)

[1] Data from Green Bay only.

[2] Includes data from Green Bay and Northern Lake Michigan.

to June, increased in July and August, then remained nearly constant through November. The trend in the fluctuations of the values of K for the females taken in 1932 was identical with that of the males taken the same year. When the data for all males are combined, it is seen that condition declined from May to June, remained constant during July, increased from August through October, and declined again in November. The values of K for the combined collections of females increased from April to May, remained nearly constant through July, increased each later month through October, and declined in November. The lower values of K for both sexes in November was the result of the large number of individuals taken in 1930, when the condition was poor.

SEX RATIO AND MATURITY

The number of males and females and the percentage of females occurring in each age group of the longjaws are given in Table 13. (The sex was determined for 316 of the 320 specimens taken in 1923 and for 57 of the 58 individuals in 1928.) Despite the fact that the one fish assigned to age-group IX was a male, it is apparent that the percentage of females in the 1923 sample increased as the fish became older. The slight decrease in the percentage of females with increased age in the 1928 age groups represented by more than one fish is perhaps the result of the small size of the sample or it well could be associated with the concentration of fish during the spawning season, since these fish were taken in November.

TABLE 13.—*Number of male and female longjaws and the percentage of females in each group of the 1923 and 1928 samples from Lake Michigan*

Age group	1923			1928		
	Number of males	Number of females	Percentage of females	Number of males	Number of females	Percentage of females
II..	4	9	69.2	2	5	71.4
III..	17	47	73.4	10	21	67.7
IV..	43	128	74.9	6	12	66.7
V..	7	27	79.4	0	1	100.0
VI..	2	18	90.0	–	–	–
VII..	0	9	100.0	–	–	–
VIII..	0	4	100.0	–	–	–
IX..	1	0	0.0	–	–	–
Total..	74	242	76.6	18	39	68.4

Analyses of the sex ratio according to length in each age group failed to reveal any consistent trend in the relative abundance of the sexes that was associated with length. The increase in the percentage of females with increasing age in the nonspawning samples of 1923, therefore, must have been associated with age rather than with size.

The more rapid disappearance of the males as the fish become older is

TABLE 14.—*Number of male and female longjaws in Lake Michigan, and the percentage of females, according to month and year of capture*

Month	1930			1931			1932		
	Number of males	Number of females	Percentage of females	Number of males	Number of females	Percentage of females	Number of males	Number of females	Percentage of females
April	–	–	–	–	–	–	0	7	100.0
May	–	–	–	175	203	53.7	33	207	86.2
June	–	–	–	86	183	68.0	85	386	82.0
July	123	375	75.3	74	189	71.9	323	1,269	79.7
August	287	785	73.2	27	59	68.6	277	1,143	80.5
September ..	–	–	–	58	134	69.8	54	195	78.3
October	–	–	–	59	226	79.3	–	–	–
November ..	133	264	66.5	12	26	68.4	–	–	–
All months..	543	1,424	72.4	491	1,020	67.5	772	3,207	80.6

not an uncommon phenomenon and has been found among the chubs by Van Oosten (1937) for the longjaw (*L. zenithicus*) of Lake Superior, by Jobes (1943) for Reighard's chub (*L. reighardi*) of Lake Michigan, and by Deason and Hile (1947) for the kiyi (*L. kiyi*) of Lake Michigan. The only one of the chubs studied so far that has failed to show a more rapid disappearance of the males with increase of age is the bloater (*L. hoyi*) of Lake Michigan (Jobes, 1949). Such a differential mortality may be due either to differences in the rate of destruction by the fishery or to an earlier death of the males from natural causes. The failure to demonstrate conclusively that the longer of the younger longjaws were predominantly males, which would thereby permit an earlier, more rapid destruction of fish of that sex by the fishery, makes it seem probable that the differential mortality of the sexes was due primarily to natural causes.

The data on the sex ratio of all longjaws for each month of each of the years 1930–1932 are presented in Table 14. Although nets with meshes of 2⅜ and 3 inches were employed in 1930 and 1931 but not in 1932, the use of all data for the first two years is justified, since there were no consistent differences between the percentages of females in the catches by nets with different sizes of mesh. In southern Lake Michigan (1930 and 1931 data) the percentage of females varied little with the years during the three months for which comparisons can be made. Neither did the grand average percentages (72 and 68) differ greatly in the two years. In May 1931 the percentage was relatively low and in October it was relatively high, but in the other months it remained more or less constant. In 1932 there was a definite trend for the females to become relatively less abundant in each month from April through September, when the collecting season ended. The percentage of females was always higher each month in 1932 than in either of the other two years. Whether or not this higher percentage was the result of annual fluctuations in sex ratio, differences in populations inhabiting different sections of the lake, or to changes in sex ratio due to greater age of the specimens cannot be determined definitely from these data. The greater size of the longjaws taken in 1932 (Table 4), and hence their probable greater age (Tables 5 and 6), suggests that these fish may have had a higher percentage of females than those taken in 1930 and 1931 because of the presence of more of the older individuals.

The great majority of the longjaws examined in 1923, 1928, and 1930–1932 was sexually mature. Only six males and eight females were designated as immature or nonspawning. The standard lengths and weights of the immature or nonspawning males ranged from 252 to 303 millimeters and from 206 to 397 grams (11.8 to 14.1 inches, total length, and 7¼ to 14 ounces), whereas corresponding values for the immature or nonspawning females were 241 to 287 millimeters and 177 to 312 grams (11.2 to 13.4 inches, total length, and 6¼ to 11 ounces).

SPAWNING SEASON

Koelz (1929) believed that the longjaws taken November 19, 1920, off Michigan City, Indiana, would have spawned soon, probably in the vicinity, although no fish with ripe eggs were found. He reported the testimony of fishermen that chubs (probably longjaws) come into shallow water in the northern part of the lake to spawn in late October and November.

The collections made in 1928 and 1930–1932 do not include any catches from a spawning concentration of longjaws, but they do provide some information that confirms November as the probable spawning time. The sample obtained on November 10, 1928, contained 39 females of which 30 were ripe and 9 were mature. All of the males taken that date were mature. Spent females were taken off Sheboygan, Wisconsin, in 38-50 fathoms of water on October 16, 1931, and off Racine, Wisconsin, in 42 fathoms on November 8, 1930. Spent males were taken on November 12, 1930, of Waukegan, Illinois, from 34–45 fathoms of water; this lift contained 23 male longjaws of which 9 were spent and 11 were ripe, but the females were all designated simply as mature.

The earliest dates on which ripe females were recorded were: August 5, 1930, one fish off Ludington, Michigan, from 26–27 fathoms; September 11, 1931, one fish off Port Washington, Wisconsin, from 75–76 fathoms; and July 9, 1932, one specimen off Manistique, Michigan, from 64–68 fathoms. The earliest date on which a ripe male was recorded was October 20, 1931; it was taken off Milwaukee, Wisconsin, in 32–36 fathoms of water. A male longjaw taken August 17, 1932, off Charlevoix, Michigan, from 54–73 fathoms, was designated as "nearly ripe."

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THE EFFECTS OF DEFLECTORS IN A SECTION OF A MICHIGAN TROUT STREAM[1]

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Abstract

The changes in angling produced by current deflectors in a 1,605-foot section of Hunt Creek, a Michigan brook trout (*Salvelinus fontinalis*) stream, were studied over an 8-year period, 3 years before and 5 years after placement of the devices. Data on changes in the physical character of the stream, the fish population, and the bottom food supply also are presented for 1 year before and 3 years after installation of deflectors. The methods used to measure these various changes are given.

Installation of 24 pool-forming deflectors raised the number of good pools from 9 to 29, increased the average pool depth by 6 inches, and exposed additional gravel without significantly changing the average stream depth over the entire section. Preliminary and unpublished bottom-food studies indicated a decrease in total number and volume of all organisms but an increase in forms found most frequently in trout stomachs. Fish-population studies demonstrated slight increases in the number of smaller trout present after the addition of deflectors, attended by a slight decrease in average size. Average creel-census figures for the 3 years prior to stream improvement and the 5 years after show an increase after improvement of 120 percent in the total catch and of 46 percent in pounds caught per hour coincident with a 64 percent increase in angling pressure. It was demonstrated that migration into the section improved was not responsible for the increases noted, also that bordering sections failed to have fishing comparably good to that produced in the improved section. It was concluded that the improvement in brook trout fishing in the experimental section was the result of an increase in number, size, and depth of pools created by installation of current deflectors.

Introduction

The purpose of this investigation was to determine as accurately as possible the effects of the addition of current deflectors upon the number and depth of pools, the fish-food supply, the fish population, and the yield to the angler in a section of a small Michigan brook trout stream.

The use of deflectors and other so-called stream-improvement devices was advocated by Hubbs, Greeley, and Tarzwell (1932), on the theory that properly located structures would better the habitat for trout and thereby increase the yield of fish. At the time their publication was issued there had been no experiments to measure the actual results of such work although several hundred devices had been installed and were then under observation to learn the permanence and effectiveness of the different types used. Tarzwell (1937) subsequently reported on the physical and biological changes following improvement in portions of six Michigan trout streams where numbered structures had been installed 5 years previously. Tarzwell (1938) compared food production, fish yield, and growth rate in two Arizona streams which he considered very similar in character. One was improved by the placement of a number of dams and the other was the control. Madsen (1938) made a rather general survey of stream-improvement structures installed in the intermountain region but lacked data for a critical evaluation of the work. Hunter, Thorpe, and Grosvenor (1940) described the effects over a 2½-year period of placing a single dam in a Connecticut stream, using the area above the influence of the structure for comparison.

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[1] Contribution from the Michigan Institute for Fisheries Research

Hunt Creek, where the present experiment was conducted, is a tributary of the Thunder Bay River in Montmorency County, Michigan. The stream is approximately 12 miles long from source to mouth. The flow is relatively rapid through much of its course. The surrounding country is hilly or swampy and the soil is generally of sand and gravel or peat. Streamside vegetation varies with the soil type, but aspen is probably predominant with some mixture of pines and hardwoods in the uplands and typical swamp conifers (white cedar, tamarack, balsam, and spruce) in the lowlands. Springs feed the stream at intervals from the source to near the mouth. A more detailed account of the ecology of Hunt Creek has been given by Shetter and Leonard (1943).

In 1939, approximately 2 miles of stream near the headwaters were selected (Hazzard, 1940) for intensive studies of the life history and management of the brook trout (*Salvelinus fontinalis*). This portion of the stream has been kept under constant observation since that time by a resident staff of fishery biologists. After preliminary examination the stream was divided into sections based upon physical characteristics, and signs were erected marking the boundaries. The entire stream in the experimental area was mapped to show the stream channel, water depths, bottom types, and existing shelter for fish.

DESCRIPTION OF THE EXPERIMENTAL SECTION

One of the experimental sections, 1,605 feet long, and designated as Section B, was selected for a study of the effects of pool-forming deflectors. In this part of its course Hunt Creek flows through a swamp and has a border of tamarack, balsam, spruce, and poplar. The flow is moderately rapid (about 1.5 feet per second in mid-channel) and before improvement was shallow with few pools. Undercut banks and submerged logs (part of them old CCC stream-improvement structures) provided rather scant shelter for fish. The bottom is largely of moderate to fine gravel and sand, with some muck in the quiet water along the edge.

Sparse growths of *Chara* and *Veronica* are found near the margins in a few places. The brook trout and the muddler (*Cottus cognatus*) are the principal species of fish. Other fish occasionally taken are the mudminnow (*Umbra limi*), the brook stickleback (*Eucalia inconstans*), the bluntnose minnow (*Hyborhynchus notatus*), the fathead minnow (*Pimephales p. promelas*), the northern redbelly dace (*Chrosomus eos*), and the blacknose shiner (*Notropis h. heterolepis*).

METHODS

Plans for the experiment were made by Dr. Justin W. Leonard (then in charge of the Hunt Creek Fisheries Experiment Station), and the authors. The senior author has been in immediate charge of the creel census at Hunt Creek and became acting director of the Station in February 1943.

Mapping.—Three maps of the experimental area were made: one on May 23-24, 1939, when remains of nine log wing deflectors installed by Civilian Conservation Corps crews persisted; one in October 1943 after 24 wing deflectors were installed; and one in 1944. Maps were constructed at a scale of 20 feet to the inch with plane table and alidade, and all distances were chained or determined by stadia readings. Cross sections of the stream were made at regular intervals and intermediate soundings were taken where changes in profile or anticipated future needs made additional information on depth desirable. Bottom soils, bars, logs, stream velocities, timber types, and log sizes were noted on maps. On October 30, 1943, 10 days after the second mapping a stream gage was installed about a mile below the test section and a reading of 1.4 feet obtained. At 300-foot intervals along the test section permanent reference stakes were set.

Installation and costs of improvement structures.—In September 1941 23 wing deflectors and in 1943, 1 deflector, were installed in the test section, or one structure for each 70 feet of stream. They consisted of 22 single-wing, 1 double-wing, and 1 diversion deflector. The typical structure was a rectangular log crib 30 inches by 30 inches by 25 feet and two or more logs high (Fig. 1). The logs were wired and stapled to posts placed with a hydraulic jet. Log spreaders were placed at intervals along the structure. The interior space was filled with gravel, sand, sod, and earth, and the top well sodded to prevent surface erosion and to improve the appearance. Wings were installed at an angle of 35° to 45° to the center thread of the stream with the terminal end downstream from the base.

The total cost of the 24 deflectors together with maintenance to the end of 1946 amounted to $512.16. Of this amount, $130.00 constituted the maintenance costs for the 5-year period, leaving $382.16 as the original construction cost, or $15.50 as the average cost per unit. The average annual maintenance cost for each structure was $1.09, a figure we believe will decrease as the bars formed behind the wings become stabilized by vegetation. The highest water for the period 1938 to 1946 occurred on June 1, 1944, when a gage reading of 2.45 feet was recorded. This

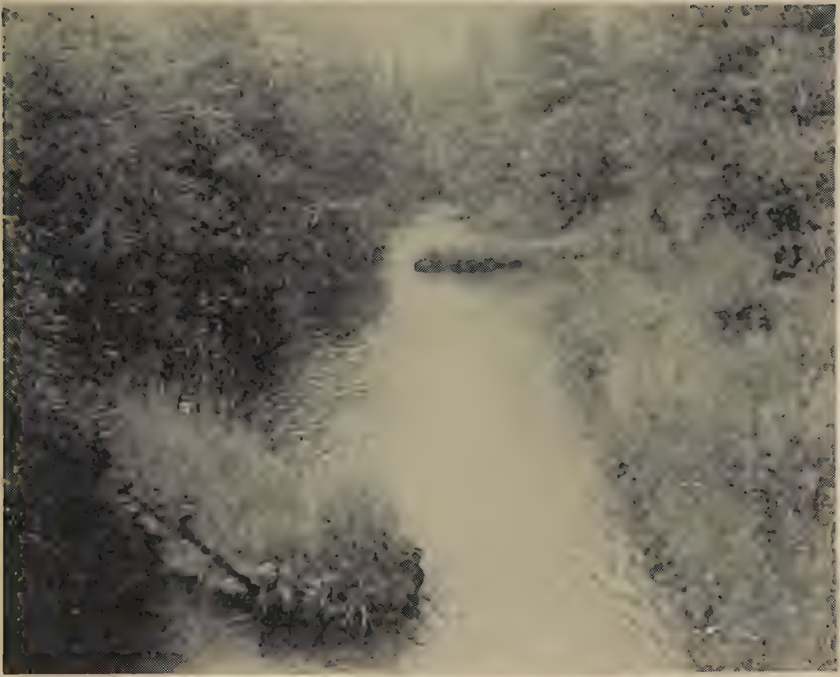

FIGURE 1.—A typical view of Section B of Hunt Creek after installation of wing deflectors.

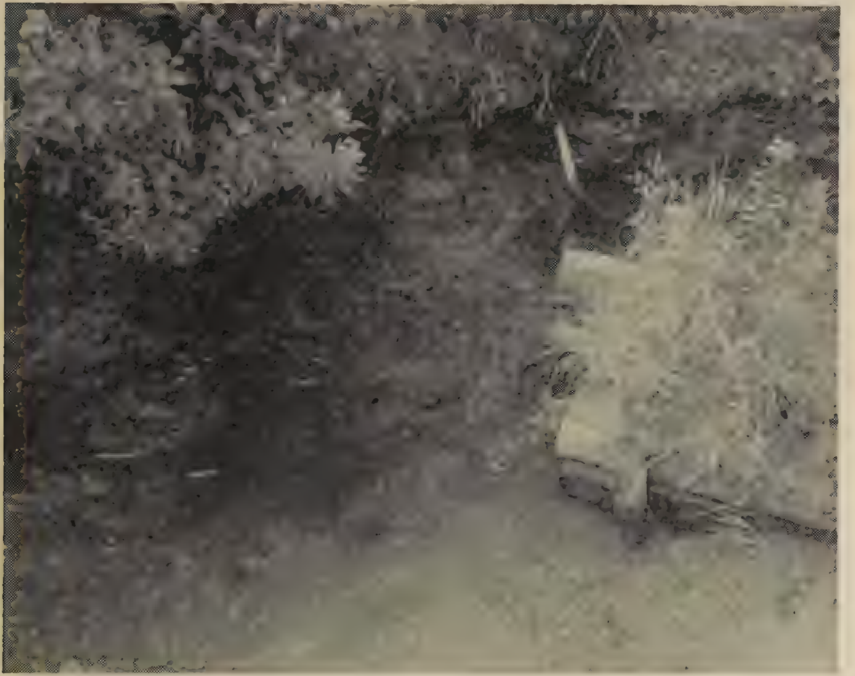

FIGURE 2.—Single-wing deflector in Section B of Hunt Creek.

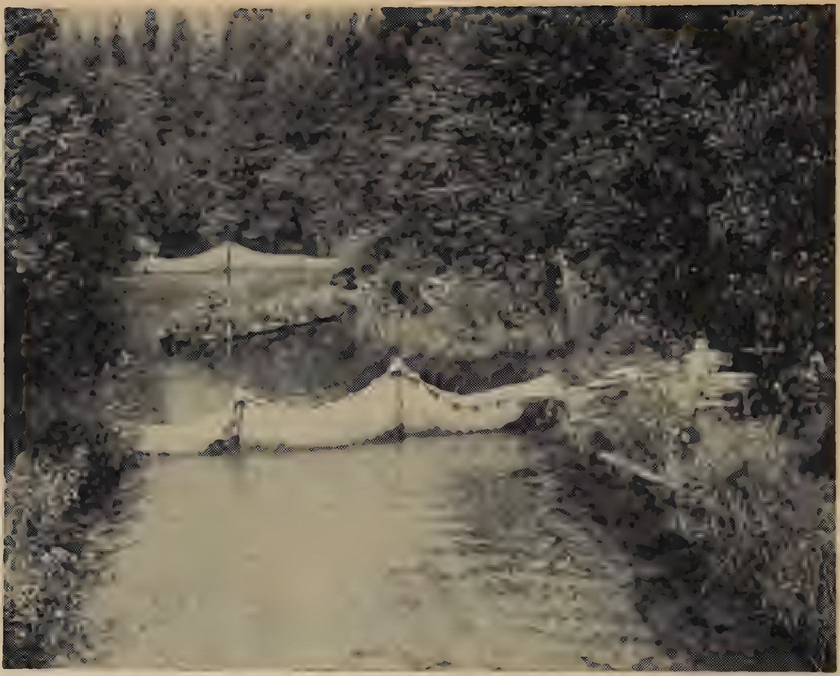

FIGURE 3.—Portion of Section B prepared for population study by means of electric shocker. Blocking seines were placed at either end of sample area; shocker unit is at base of deflector in middle background.

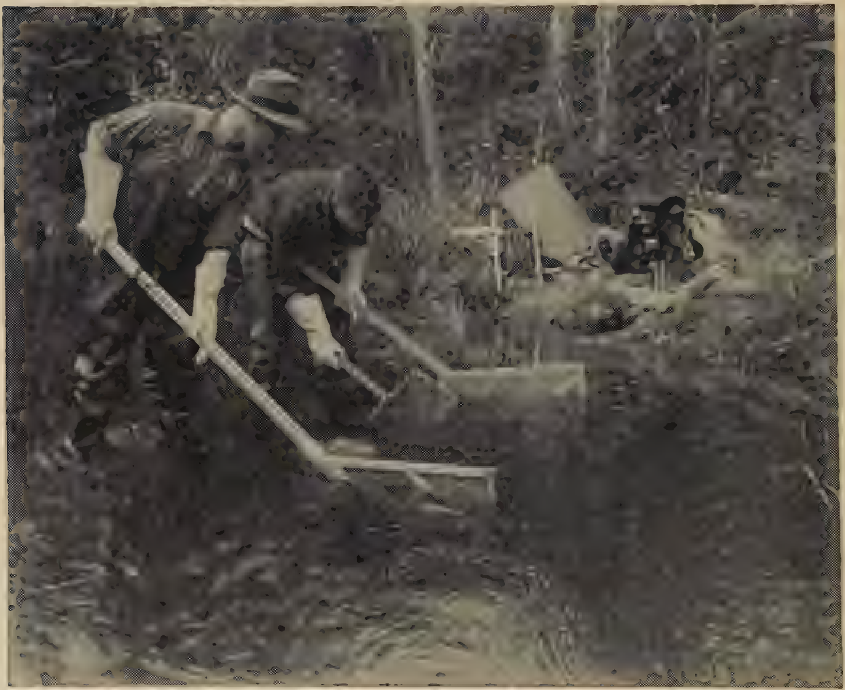

FIGURE 4.—Use of electric shocker in population study of trout stream.

flood caused damage requiring more than average repair, in some structures necessitating the lifting of the sod to replace washed-out material.

Food and fish-population studies.—The effect of the deflectors upon the food supply of brook trout was measured by the comparison of square-foot samples of the bottom fauna taken from September 17 to October 15, 1941, prior to the improvement, with similar samples taken at approximately the same time of year in the 3 years after the structures were placed. Twenty sampling stations were selected in areas which presumably would be affected by the deflectors. The folding square-foot device described by Surber (1937) was used to secure the samples. Organisms were measured volumetrically by water displacement and usually identified to species. Stomach examinations and studies of the fauna in the other parts of the stream contributed to this investigation.

Sample counts of the fish population were made in August 1941, 1942, 1943, and 1944. Theoretically, the 1941 count represents the fish population for an unimproved stream area, and the counts for succeeding years represent fluctuations in the population caused by the habitat changes resulting from the installation of pool-producing deflectors.

Five different stretches of Section B, varying in length from 60 to 83 feet and in width from 13 to 23 feet, considered to be representative of the stream conditions originally found there, were selected as sampling areas for the long-term study and marked with stakes. Each year during late August these sections were blocked off by fine-meshed seines (¼- and ⅜-inch bar measurements, 40 to 60 feet long and 6 feet deep) staked to the stream bottom. The fish populations of the blocked-off portions were then removed and counted, weighed, and measured by species. All brook trout captured were measured individually and all longer than 4 inches were weighed individually. The fingerling brook trout were weighed in groups of 10 fish. Scale samples have been preserved from all brook trout longer than 7 inches, and from a good random series of those below this legal length. All fish taken were returned alive to the stream except for a small number killed in the process of capture or handling and retained for stomach analysis. It is believed therefore that the sampling has had little if any influence on the final results.

Two methods of obtaining the fish populations from the sample sections have been used. In 1941, the sample areas within Section B were blocked off and the enclosed populations removed by intensive seining for 3 to 5 hours per section with common-sense seines and 8- by 6-foot, ⅜-inch-mesh seines, the method described by Shetter and Hazzard (1939). In 1942, 1943, and 1944, the electric "shocker," modified somewhat from that described by Haskell (1940), was used in the collection of the fish from the blocked-off areas (Figs. 2 and 3).

Shetter and Leonard (1943) demonstrated that by intensive seining it is possible to capture only about 90 percent of the total number of trout present, even under the best conditions. The remaining 10 percent of the population consists mainly of fish belonging to the smaller size groups. Consequently, the actual counts of smaller fish obtained for 1941 are probably somewhat low and the observed results were corrected accordingly from data obtained by Shetter and Leonard (1943). However, the sample counts for 1942, 1943 and 1944, when the "shocker" was used, are probably very close to the actual number of fish present. Thirteen tests with from 12 to 40 marked fish introduced into the sample sections after they were blocked off indicate that the "shocker" has an efficiency of 100 per cent for brook trout 7 inches long or larger, 94.4 percent for brook trout 4 to 7 inches long, and 96.2 percent for fingerling brook trout under 4 inches in size, or an over-all average efficiency of 95.7 percent for fish of all sizes.

Since the five sample areas studied were the same each year, the changes in the actual populations of the sample areas may be taken to indicate increases or decreases in the fish population of Section B. The actual numbers of fish given in the tables are the totals obtained from 366 lineal feet of Section B. An area of 7,360.8 square feet (0.169 acre) was sampled, or approximately one-fourth of the total area of Section B.

Creel census.—Starting with the trout fishing season of 1939, complete records of the catch were secured for the entire 2 miles of stream in the Hunt Creek experimental area. Creel-census clerks employed and trained by the Institute interviewed fishermen and examined the fish taken by them. Almost all of the fish were measured and weighed individually and the catch and the time spent fishing in each section were recorded. The data secured represent the yield of the stream for 3 years prior to installation of the deflectors and for 5 years thereafter. Hence any major changes in the quality of fishing can be attributed to the modification in the environment produced by the deflectors. The trout season has varied from 129 to 136 days in the period 1939–1946, since it opens the last Saturday in April and extends through Labor Day. There was no change during the period in the regulations as to size, creel limit, or otherwise. The fishing pressure varied somewhat because of war-time travel restrictions and with the increased popularity of the improved section, but not enough to affect the experiment as it has been conducted.

RESULTS OF INSTALLATION OF DEFLECTORS

Physical changes.—In 1939, soundings were taken at locations where 13 structures were subsequently placed. The average maximum depth at these locations in 1939 was 1.52 feet (Table 1). The same locations in 1943 showed an average maximum depth of 2.07 feet, and in 1944 of 2.08 feet, representing an average increase of 0.55 foot per pool by 1943 and no significant further increase the following year. Tarzwell (1937) found the average increase in pool depth in five Michigan streams resulting from deflector installation was 13.2 inches. In general, material was swept from the pool floors by the deflector-accelerated current which also tended to concentrate the coarser gravel over the pool-bed area below the structure.

TABLE 1.—*Change in stream-pool depths of Hunt Creek, Section B, 1939,*

[Structures were installed in the fall of 1941]

Pool and deflector number	Maximum depth in feet in 1939	Condition in 1939	Maximum depth (feet) in 1943	Change in depth (feet) over 1939	Maximum depth (feet) in 1944	Change in depth (feet) over 1939	Pool area (square feet) in 1944
1	2.0	...	1.7	−0.3	1.9	−0.1	80
2	No record	No pool	2.5	...	2.4	...	600
3	No record	No pool	2.5	...	2.4	...	
4	1.6	...	1.9	+0.3	2.0	+0.4	200
5	1.6	...	1.5	−0.1	2.7	+1.1	60
6	0.6	No pool	2.0	+1.4	2.1	+1.5	100
7	2.0	...	3.3	+1.3	3.3	+1.3	160
8	No record	No pool	2.0	...	2.2	...	200
9	No record	No pool	1.4	...	1.8	...	160
10	2.0	...	2.1	+0.1	2.0	0	200
11	No record	No pool	2.0	...	1.4	...	80
12	1.0	No pool	2.0	+1.0	1.5	+0.5	120
13	No record	No pool	3.3	...	3.0	...	320
14	No record	No pool	2.5	...	2.4	...	240
15	2.0	...	2.2	+0.2	2.2	+0.2	440
16	1.8	...	1.9	+0.1	1.7	−0.1	120
17	0.7	No pool	1.8	+1.1	1.6	+0.9	280
18	No record	No pool	2.4	...	2.4	...	1,600
19	No record	No pool	3.0	...	2.8	...	
20	1.0	No pool	2.3	+1.3	2.3	+1.3	
21	No record	No pool	1.5	...	1.5	...	200
22	2.0	...	2.6	+0.6	2.2	+0.2	240
23	No record	No pool	1.9	...	1.6	...	240
24	1.5	...	1.6	+0.1	1.6	+0.1	80
Total	...	...	...	...	...	...	5,720
Average	1.52	...	2.07	...	2.08	...	238
Average change over 1939, in sites for which data are available for the 5–year period			...	+0.55	...	+0.56	...
Minimum total increase in pool area[1] .			...	...	...	...	4,140

[1] Based on gains over areas listed in Column 3 as containing no pools prior to improvement

Tarzwell (1937) recorded an average area of gravel uncovered by deflectors of 266 square feet on the Little Manistee River; 144 square feet on the East Branch of the Black River; 122 square feet on Gamble Creek; 542 square feet on the Pigeon River; and 18 square feet on the West Branch of the Sturgeon River. Little change is apparent in the bottom-soil types of Section B of Hunt Creek, except for increased deposition of silt behind the wing structures and sand-bar formation downstream from the terminal end of several wings. At the time of the original survey there were 9 pools that were judged to be capable of harboring legal-sized trout. Two of these pools were excellent, but the others were shallow and of very limited extent. In 1944, there were 29 pools, all of considerable size. The depth of two of the original 9 pools had become reduced to a point where they are not now classed as pools. New deflectors were installed at the sites of 5 of the old devices and 2 pools were undisturbed by new construction, leaving a total of 19 pools that have been added to the experimental area. Five of the original 9 pools have been expanded considerably by the wing deflectors. The total pool area as computed in 1944 was 5,720 square feet, a ratio of pool area to total stream area of 1 to 5.2. Although the original pool area was not determined, the 2 best pools at the time of the 1939 survey, upon which no subsequent improvement was placed, have not significantly increased in area. The 5 pools near which new structures were installed have materially increased in both depth and area. The average area per pool (1944 figures) was 238 square feet.

Based on all soundings, the average depth in the section was 1.29 feet in 1939 and 1.30 feet in 1944. This change was too small to be significant assuming the water stage was approximately the same at the time of both surveys. No water stage was recorded in 1939, but there is considerable evidence that the water at that time was substantially at the same stage as in 1944. The maximum depth of the pool below the dam at the upper end of the section was 0.1 foot greater in 1944 than in 1939. This pool was unaffected by any of the improvement structures placed below. Several areas between structures retained approximately their same depths for the two periods, indicating but slight change in water stage for the 1939 and 1944 survey periods.

Considerable movement of sand and silt has occurred near the structure sites. Most of the finer sediments have been deposited in the back-water area behind the wings and smaller amounts at the angle where the upstream edge of the wing deflector intersects the bank. Coarser sediments (largely sand) have been deposited in bars paralleling the current and extending from a point near the outer end of the deflector downstream for variable distances depending on current velocity. Below the double-wing deflector and the diversion structure, sand and gravel have been deposited at right angles to the current where the velocity of flow is sufficiently lessened to prevent further transport. The bar thus formed has emerged above normal water flow and some vegetation has become established on it. Removal of the finer sediments by current action has exposed additional gravel bottom in the stream area where more rapid flow predominates.

The character of the banks, the generally stable water level, and good marginal cover have eliminated the necessity for bank protectors. The sod placed on the deflectors has become well rooted, providing a stable cover for the deflectors and giving them a pleasing natural appearance. In a few, undercutting and settling of the earth fill has occurred, mostly following the 1944 flood. Replacement of fill accounts for the major portion of the maintenance costs. Subsequently it has been found that sheet piling extending back 4 to 6 feet from the stream end of each deflector prevents undercutting and settling of the earth and sod.

The total area of the experimental section as measured from the maps by polar planimeter underwent little significant change. In 1939 the computed area was 30,124 square feet, or 0.69 acre. In 1943 and 1944, areas were 30,960 and 29,640 square feet, or 0.71 and 0.68 acre respectively. The 1943 and 1944 measurements included the area of the installed structures.

To judge from the average depth and area of the entire section before and after improvement, cutting and deposition caused by the deflectors is local. Excavation to form pools has been equalized by deposition of sediment in bars below pools or on the upstream or downstream shoreward end of the deflectors. This process may be considered as controlled resedimentation which directs the shifting bottom materials into areas where they may eventually become stabilized by the growth of marginal vegetation.

Effects on aquatic insects.—Dr. Leonard's annual surveys of bottom fauna were interrupted by his entry upon military duty early in 1943. From the South Pacific, Captain Leonard wrote in 1944:

> For some time after improvement devices were installed, a decrease in total number and volume of bottom organisms was noted. A decrease appeared logical in view of the considerable physical disturbance incident upon the work of construction. During the late fall and winter months of 1942–43, however, faunal recovery was apparent. It was gratifying to note that a favorable change in species-occurrence ratios was taking place. Certain species of Trichoptera and Chironomidae, and the scud, *Hyalella,* apparently favored items of trout diet in Hunt Creek as evidenced by stomach analyses, were taken in greater quantity than before improvement. Nymphs of the stonefly *Isogenus*, and larvae of the snipe-fly *Atherix,* both predaceous forms seldom encountered in trout stomachs but locally dominating the bottom fauna in Section B prior to improvement, had shown but little tendency to invade the area. Thus, at the time the study was interrupted, while the total number and bulk of bottom organisms were still slightly less than prior to improvement, the number and bulk of organisms of proven value in trout nutrition were greater than before, the overall loss being largely at the expense of species of dubious value in the trout-food cycle. This situation greatly encouraged me in my conviction that, with further knowledge of the trout-food cycle and of the ecological requirements of its essential components, environmental-control measures can be perfected to restrict a stream's basic productive capacity in very large measure to the support of organisms entering directly into the trout-food cycle.

TABLE 2.—*Actual numbers of fish and crayfish found in the five population-study areas of Section B, Hunt Creek, in August 1941, 1942, 1943 and 1944*

[Figures in parentheses were determined by applying corrections as outlined in text]

Item		1941		1942		1943		1944	
		Number	Weight (pounds)	Number	Weight (pounds)	Number	Weight (pounds)	Number	Weight (pounds)
Brook trout	legal[1]	...	....	...	....	1	0.14	4	0.59
		...	....	...	....	(1)	(0.14)	(4)	(0.59)
	illegal[1]	84	3.26	71	3.02	99	4.56	133	4.94
		(99)	(3.84)	(75)	(3.19)	(105)	(4.84)	(141)	(5.24)
	fingerling[1]	369	3.34	430	3.26	432	2.81	421	2.69
		(430)	(3.89)	(447)	(3.39)	(449)	(2.92)	(438)	(2.80)
Total brook trout		453	6.60	501	6.28	532	7.51	558	8.22
		(529)	(7.73)	(522)	(6.58)	(555)	(7.90)	(683)	(8.63)
Muddlers		17	0.05	9	0.09	19	0.22	33	0.27
Other fish		10	0.08	14	0.07	13	0.11	18	0.08
Crayfish		29	[2]0.78	4	0.10	10	0.32	9	0.36
Grand totals		509	7.51	528	6.54	574	8.16	618	8.93

[1] Legal trout are 7 inches total length or longer, illegal trout are those between 4.00 and 6.9 inches, fingerling trout are less than 4 inches

[2] Weight of 2 crayfish not included

The collection of bottom-fauna samples has been continued and the analyses will be made the subject of a separate publication.

Changes in the fish population.—Results of sample population counts taken the year prior to improvement and each year thereafter from the same five areas are presented in Table 2. Brook trout and muddlers were the predominant forms encountered. Small numbers of creek chubs, bluntnose minnows, blacknose shiners, fathead minnows, redbelly dace, mud minnows, and sticklebacks were also present. Crayfish varied in numbers, but have never been particularly abundant.

The total brook trout population of the sample areas has shown a slight increase since the installation of the pool-forming deflectors. In 1941, the sample counts revealed 453 brook trout. In 1942, after the deflectors had been in place for 10 months, 501 brook trout were counted. In 1943 and 1944, the numbers of brook trout listed from the sample areas were 532 and 558 respectively. Except for a drop between 1941 and 1942, the total weight of the brook trout captured also has increased as follows: 6.60 pounds in 1941; 6.28 pounds in 1942; 7.51 pounds in 1943; and 8.22 pounds in 1944.

Seventeen muddlers which weighed 0.05 pound were encountered in 1941. In 1942, 9 muddlers weighing 0.09 pound were taken, whereas in 1943 and 1944, the numbers taken were 19 and 33 with corresponding increases of weight. Apparently the changing bottom conditions after the installation of the deflectors in 1941 had some influence on this species also. Only 8 more minnows were taken in 1944 than in 1941. The total number captured has varied between 10 (1941 count) and 18 (1944 count). Their total weight has varied between 0.07 and 0.11 pound.

Crayfish appear to have been more abundant under stream conditions prevalent in 1941, when 29 individuals weighing 0.78 pound were captured. In 1942, 4 individuals weighing 0.10 pound were noted, and in 1942 and 1943, 10 weighing 0.32 pound and 9 weighing 0.36 pound were taken, respectively. After the bottom becomes more stabilized, however, the original numbers and weight of crayfish may again be reached.

In 1941 and 1942, no legal-sized fish were captured in population studies in the sample sections. The explanation for failure to take any legal brook trout in Section B in these years is believed to be that legal-sized fish were very scarce. However, in 1943 one legal fish (weight 0.14 pound) was captured, and in 1944 four legal fish (total weight 0.59 pound) were taken aside from those removed by angling. Although the evidence with regard to legal-sized brook trout in the sample areas under consideration is not conclusive, it does indicate an increase in numbers of legal-sized fish. Better evidence as to the increase in numbers of brook trout larger than 7 inches is available from the creel-census data.

In Table 2, in parentheses, will be found the number of brook trout estimated to have been present in the various years. The actual numbers counted have been corrected as follows: 1941 data obtained by block-and-seine technique were amended in accordance with observed percentages of the total brook trout population obtained by Shetter and Leonard (1943) by seining; 1942, 1943, and 1944 data were corrected by percentages of efficiency observed during those years from 12 marking-and-recovery tests of a limited nature, see p. 000). No data on the efficiency of the shocking are available for muddlers, crayfish, and other fish; accordingly the actual numbers found are used. Except that the data were obtained by block-and-seine technique in 1941, and in subsequent years by use of the shocker, the samples are comparable.

With the exception of 1942, the illegal brook trout (those from 4 to 6.9 inches, total length) increased in the years following the placement of the deflectors. The numbers and weights of illegal brook trout were: 99 fish (weight, 3.84 pounds)[2] in 1941; 75 fish (3.19 pounds) in 1942; 105 fish (4.84 pounds) in 1943; and 141 fish (5.24 pounds) in 1944. The fingerling brook trout (those less than 4 inches, total length) have fluctuated in the yearly samples. From 430 fingerlings estimated in 1941, they have varied as follows: 447 in 1942; 449 in 1943; 438 in 1944.

TABLE 3.—*Average size of brook trout captured in the five sample areas of Section B, Hunt Creek, for each year of the population studies*

[Lengths recorded in inches, weights in ounces]

Size group and item	Year			
	1941	1942	1943	1944
Fingerling (less than 4 inches)				
Average length	2.97	2.78	2.64	2.68
Range in length	2.20–3.94	2.13–3.94	1.97–3.86	1.81–3.94
Average weight	0.14	0.12	0.11	0.10
Illegal (4–6.9 inches)				
Average length	4.90	4.99	4.97	4.71
Range in length	3.98–6.93	3.98–6.81	3.98–6.89	3.98–6.89
Average weight	0.62	0.68	0.74	0.60
Legal (7 inches and greater)				
Average length	...	...	7.05	7.41
Range in length	...	...	...	7.36–7.48
Average weight	...	...	2.22	2.37

The average size of individuals of each group has undergone slight changes (Table 3). In 1941, fingerling brook trout averaged 2.97 inches in length and 0.14 ounce in weight. By 1943, however, this size group of fish averaged only 2.64 inches in length and 0.11 ounce in weight. A slight increase to an average length of 2.68 inches attended by a decrease in average weight to 0.10 ounce occurred in 1944.

The illegal brook trout in 1941 were of an average size of 4.9 inches and 0.62 ounce. In 1942 and 1943, for all practical purposes they had the same average size (1942—4.99 inches and 0.68 ounce; 1943—4.97

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[2] The comparative figures given here are based on the data corrected as explained in the preceding paragraph.

inches and 0.74 ounce). A decrease in the average size of trout belonging to this size group took place in 1944, when the average length was only 4.71 inches and the average weight 0.60 ounce. The legal-sized brook trout captured were too few to permit any comparison.

The reasons for the decreases in the average size of brook trout in some size groups may be more readily understood if the arbitrary size groups into which they were separated are broken down still further, as has been done in Table 4, where the number of trout in each 1-inch grouping from 2 to 7 inches is given. It will be noted that there were increases in the numbers of fish in the 0.0–1.9-inch, 2.0–2.9-inch, 4.0–4.9-inch, and 5.0–5.9-inch size groups and decreases in the 3.0–3.9-inch size group. The 6.0–6.9-inch size group has fluctuated only slightly. These changes would tend to lower the average sizes of the arbitrary groupings.

TABLE 4.—*Size-frequency distribution of brook trout captured in the population study areas of Section B, Hunt Creek, 1941–1944 inclusive*

[In parentheses are numbers of fingerlings which escaped measurement]

Size group	Size range (inches)	Number in size group in year			
		1941	1942	1943	1944
Fingerlings . . .	0.0–1.9	. . .	. . .	1	3
	2.0–2.9	211	326	357	346
	3.0–3.9	158	102	74	72
Illegals	4.0–4.9	58	38	57	94
	5.0–5.9	15	26	30	29
	6.0–6.9	10	6	12	8
Legals	7.0–7.9	. . .	. . .	1	4
Totals	All sizes	452(1)	498(3)	532	556(2)

The habitat changes produced by the deflectors apparently have made possible the survival of a larger number of brook trout between the lengths of 2 and 6 inches as well as an increase in the number of brook trout larger than 7 inches.

Similar increases in a stream fauna have been noted by other researchers but very little has been recorded in the literature concerning the changes in the fish population of an improved area after installation of improve-

TABLE 5.—*Summary of marking data on wild brook trout seined and fin-clipped above and below Section B of Hunt Creek before deflectors were installed, September 1941*

[The dorsal and right pectoral fins were clipped in Section A and the dorsal and left pectoral in Section C]

Stream section	Number and average total length (inches) of brook trout marked			Total fish marked
	Fingerlings	Illegals	Legals	
Section A	147	113	1	261
	(3.3)	(5.1)	(8.2)	. . .
Section C	154	93	2	249
	(3.3)	(5.0)	(7.0)	. . .

ment devices. Tarzwell (1937), in his original work on Michigan trout streams, considered the point, but was unable to conduct enough counts in sample areas before and after the installation of his experimental devices. He states: "It is significant, however, that in all tests made more legal trout were taken and the average size of the trout was greater after improvement."

The comparative figures in Table 2, obtained from five sample areas within Section B of Hunt Creek, provide evidence that the fish population of Section B was increased by the addition of pool-forming deflectors. Excluding the legal brook trout, because none were captured during the population studies in 1941 or 1942, the various elements of the population in study areas of Section B increased or decreased between 1941 and 1944 as follows: [3] Illegal brook trout increased 42.4 percent in number, 36.4 percent in weight; fingerling brook trout increased 1.9 percent in number but decreased 28 percent in weight; all brook trout combined increased 28.3 percent in number, 4 percent in weight; muddlers increased 94.1 percent in number, 388 percent in weight; minnows increased 80 percent in number, but showed no change in weight; crayfish decreased 69 percent in number, 54.7 percent in weight.

TABLE 6.—*Catch per seine haul of fin-clipped fish in Section A for the period, October 1941 to November 1942, inclusive*

[Numbers and letters in parentheses show numbers and section of origin of fish marked and released outside of Section A; all other recoveries had been marked and released in Section A]

Date of seining	Marked fish caught			Number of hauls	Catch per seine haul		
	Legal	Illegal	Fingerling		Legal	Illegal	Fingerling
1941							
October	0	13	2	27	0	0.48	0.07
November ...	0	3	0	44	0	0.07	0
December ...	0	5	0	45	0	0.11	0
1942							
January ...	0	1	0	20	0	0.05	0
February ...	0	0	0	30	0	0	0
April	0	0	1	37	0	0	0.03
April	0	2	0	24	0	0.08	0
May	0	11(1C)	2	40	0	0.27	0.05
June	1	4	0	38	0.03	0.11	0
July	4	3	0	30	0.13	0.10	0
August	1	3	0	33	0.03	0.09	0
September ..	2	6	0	28	0.07	0.21	0
October	4	7(1C)	0	34	0.12	0.21	0
November ...	0	2	0	28	0	0.07	0
Total	12	60(2C)	5	458	..	..	..
Average	..	..	..	...	0.03	[1]0.13	0.01

[1] Less than 0.005 for migrants from Section C

At the start of the intensive studies on Section B in the fall of 1941,

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[3] In calculating percentage increases or decreases, the corrected data of Table 2 were used.

TABLE 7.—*Catch per seine haul of fin-clipped fish in Section B for the period, October 1941 to November 1942, inclusive*

[Numbers and letters show numbers and section of origin of fish marked and released outside of Section B]

Date of seining	Marked fish caught			Number of hauls	Catch per seine haul		
	Legal	Illegal	Fingerling		Legal	Illegal	Fingerling
1941							
October	0	1A	0	25	0	0.04	0
November	0	1A	0	24	0	0.04	0
December	0	0	0	33	0	0	0
1942							
January	0	0	0	24	0	0	0
February	0	0	0	28	0	0	0
April	0	0	0	43	0	0	0
April	0	1A ; 1C	1C	32	0	0.06	0.03
May	0	1A ; 1C	1C	26	0	0.08	0.04
June	0	2A ; 1C	0	31	0	0.10	0
July	0	1C	0	35	0	0.03	0
September[1]	0	0	0	34	0	0	0
October	0	3C	0	41	0	0.07	0
November	0	1A ; 1C	0	28	0	0.07	0
Total	0	7A ; 8C	2C	404	..	..	..
Average	..	..	..	...	0	0.04 (1.02A ; 0.02C)	[2]0.00

[1] Deflectors being installed in August; no seining done

[2] Average less than 0.005

the possibility was not overlooked that the brook trout resident upstream and downstream might be attracted into the improved area. In order that any such movement might be noted, numerous brook trout of all sizes were marked by fin-clipping in Section A (immediately downstream) and Section C (immediately upstream). The dorsal and right pectoral fins were removed from 261 wild brook trout seined in Section A, and the dorsal and left pectoral fins were clipped from 249 wild trout in Section C (Table 5). Both lots of fish were returned to the stream areas of Sections A and C from which they were originally seined.

These fish were marked in September 1941. The experimental stream area was seined each month thereafter until November 1942, except for the months of March and August 1942. In the course of the seining operations records were kept of the number of seine hauls (made with an 8- by 6-foot, 3/8-inch-mesh seine) conducted in each stream section (A, B, C, and D), and of the number and size of the various marked and unmarked brook trout captured (Tables 6, 7, 8). From these data it is possible to calculate the relative abundance of the two types of fin-clipped fish on the basis of the comparative numbers of differently marked fish caught per seine haul in the three stream sections of interest to us.

The results from these periodic seinings indicate that there was a small amount of movement into Section B from Sections A and C. However, if the catch per seine haul is compared by sections and months, it will

Table 8.—*Catch per seine haul of fin-clipped fish in Section C for the period, October 1941 to November 1942, inclusive*

[All recoveries had been marked and released in Section C]

Date of seining	Marked fish caught			Number of hauls	Catch per seine haul		
	Legal	Illegal	Fingerling		Legal	Illegal	Fingerling
1941							
October	0	20	9	37	0	0.54	0.26
November	0	12	12	58	0	0.21	0.21
December	0	13	8	84	0	0.15	0.10
1942							
January	0	14	5	54	0	0.26	0.09
February	0	7	4	54	0	0.13	0.07
April	1	8	3	78	0.01	0.10	0.03
April	2	26	7	59	0.03	0.44	0.12
May	0	19	1	52	0	0.37	0.02
June	1	11	0	43	0.02	0.25	0
July	0	4	0	57	0	0.07	0
August	0	4	0	42	0	0.10	0
September	0	7	0	40	0	0.18	0
October	0	4	0	54	0	0.07	0
November	0	5	0	30	0	0.16	0
Total	4	154	49	742	..	..	..
Average	..	..	..	...	[1]0.00	0.21	0.07

[1] Average less than 0.005

be noted that for any month many more marked fish were captured per haul in the sections where they were marked than were taken in Section B.

At no time in the course of the seinings were any marked fish of legal size taken in Section B by seining, although marked legal fish were captured by seining (and also by angling) in Sections A and C. Illegal fish were taken most frequently. Considering all the seining data, the catch per seine haul in Section C of illegal fish marked in Section C was 0.21 fish, of the same marking recovered in Section B, 0.02 fish, or 10 times less. For illegal fish marked in Section A, about nine times fewer fish of that marking were recovered per seine haul in Section B than were recovered in Section A (0.13 fish per seine haul in Section A; 0.014 fish per seine haul in Section B). No fish marked as fingerlings in Section A were recovered in Section B, and only two fingerlings marked in Section C were captured in Section B.

The fin-clipped fish marked in Section C which were captured in Sections B and A are regarded as passive migrants which were current-borne to the lower habitats. A small percentage of the Section B brook trout population was derived in this manner before the installation of the devices as well as afterward, as can be proven by the results of the seining prior to 1941 for other lots of wild fish marked in Section C (unpublished data).

It is very likely that the migrants from Section A which were later caught in Section B were fish marked near the Section A-Section B border and whose normal ranges extended upstream into the lower course of

Section B. The authors believe that the small amount of passive movement and sporadic wanderings by brook trout in the neighboring stream sections have not materially increased the brook trout population of Section B since the deflectors were placed, and have influenced the anglers' catch only slightly.

Trout migration from tributary streams.—Two tributary streams enter Section B between its upper and lower limits. Tributary 3, which meets the main stream just above the lower end of Section B, is about 2½ miles long, drains one natural lake and one artifical trout pond, and flows about 400–500 gallons a minute. Tributary 4 (Fuller Creek), which enters Section B at its extreme upper end, drains East Fish Lake (a trout lake) and is 2 miles long. It flows about 5,000 gallons per minute (approximately equal to Hunt Creek where the two join). Both tributaries are trout streams but only Fuller Creek is fished.

Two-way fish traps were operated on both Fuller Creek and Tributary 3 during the course of the experiment. The records of fish captured have some bearing on the source of the increased yield of Section B; some pertinent data are given in Tables 9 and 10.

TABLE 9.—*Known numbers of brook trout of all sizes exchanged between Section B and Tributaries 3 and 4, as shown by trapping weirs at mouths of the tributaries*

Time period	Tributary 3		Tributary 4		Totals	
	Out of B	Into B	Out of B	Into B	Out of B	Into B
Aug. 15, 1939–Oct. 30, 1940	(No weir)	(No weir)	28	1,099	28	1,099
Oct. 1, 1940–Sept. 30, 1941	219	41	23	403	242	444
Oct. 1, 1941–Sept. 30, 1942	303	270	[1]70	[1]37	373	307
Oct. 1, 1942–Sept. 30, 1943	193	601	254	397	447	998
Oct. 1, 1943–Sept. 30, 1944	0	293	198	350	198	643
Totals	715	1,205	573	2,286	1,288	3,491

[1] Weir on Tributary 4 not operated Nov. 16, 1941–Aug. 10, 1942

From records of daily inspection over a 5-year period (Table 9) it would appear that population increases in Section B might have been the result of increased downstream migration from Tributaries 3 and 4 and decreased movement out of B into those tributaries (if one assumes that all fish moving downstream out of those tributaries became residents of Section B). Inspection of data for 1945 and 1946 from weir records, tag recoveries, and creel census indicated that no greater percentage of the anglers' catch in Section B in those years was composed of fish originating in the tributaries than for the previous years.

The influence of movements of brook trout from the tributaries toward Section B can be estimated from the numbers of fish tagged in the period October 1940–October 1944 and the location of ultimate recovery (Table 10).

From 548 brook trout marked moving downstream through the Tributary 3 weir, 79 have been recovered, 15 of them in Section B. The largest number was recaptured from the 138 fish marked during the 1941–1942

TABLE 10.—*Numbers of brook trout tagged moving toward Section B in Tributaries 3 and 4 in various years, and the number and locality of recovery of the tagged fish in subsequent years*[1]

[Where no figure is given, fish from the particular tagging were not available for capture]

Tributary where tagged	Date of tagging	Number of tagged trout moving toward Section B	Number of tagged brook trout recovered							
			1941		1942		1943		1944	
			In Section B	Elsewhere	In Section B	Elsewhere	In Section B	Elsewhere	In Section B	Elsewhere
Tributary 3..	Oct. 1, 1941–Sept. 30, 1942	138	0	0	8	16	1	2	0	3
	Oct. 1, 1942–Sept. 30, 1943	277	..	..	0	10	4	19	1	4
	Oct. 1, 1943–Sept. 30, 1944	133	..	..	..	..	0	0	1	10
Tributary 4..	Oct. 1, 1940–Sept. 30, 1941	202	0	0	0	1	0	1	0	0
	Oct. 1, 1941–Sept. 30, 1942	12	0	0	0	2	0	0	0	2
	Oct. 1, 1942–Sept. 30, 1943	209	..	..	0	3	1	3	1	8
	Oct. 1, 1943–Sept. 30, 1944	182	..	..	..	..	0	1	2	17

[1] Fish were recovered by means of angling, seining, weir traps, or electric shocker, and were of all sizes

season in Tributary 3, with 9 recoveries made in Section B and 21 elsewhere. A smaller proportion of the fish tagged in 1942–1943 in Tributary 3 was recovered in Section B (5 out of 277 tagged were recovered in Section B; 33 were taken elsewhere), and a still smaller proportion of the 1943–1944 marking was taken in Section B (1 of 133 marked was taken in Section B; 10 were captured elsewhere).

Records for Tributary 4 show that none of the 214 brook trout tagged in 1940–1941 and 1941–1942 were captured in Section B. From the 1942–1943 tagging of 209 fish in Tributary 4, 2 were later recovered in Section B, and 14 were recovered elsewhere. The 1943–1944 markings at Tributary 4 included 182 fish, of which 2 have been recovered in Section B and 18 elsewhere.

Although Tributary 2 enters Hunt Creek about 80 yards downstream from the lower boundary of Section B, it also has had a slight influence on the population of that experimental section. From 289 brook trout of all sizes tagged between October 1941 and October 1944 a total of 59 fish was recovered. Three of these recoveries had moved upstream into Section B and 56 were recaptured elsewhere, chiefly in Section A or further downstream.

The evidence just presented indicates that only a small part of the increases in the Section B population has been the result of downstream movement from the tributaries. No valid method of estimating the extent of the increases from the downstream migrations of any year in any tributary appears possible, since the recoveries listed in Table 10 were obtained by various methods involving different units of fishing effort (*i.e.*, it would not be proper to compare the number of recoveries made by angling with those made by seining, shocking, or trap).

The data available from the fin-clipping and subsequent seinings of native brook trout in stream sections immediately above and immediately below the improved water, plus the weir records from Tributaries 2, 3, and 4, with the tag recoveries from fish marked at those weirs, suggest that a small but unknown percentage of the population increase of Section B was due to migrations into Section B from neighboring waters (Sections A, C, Tributaries 3 and 4).

Although it would be desirable to evaluate accurately the contribution of the three tributaries and the neighboring stream areas to the population increases from 1941 through 1944, a lack of knowledge concerning the number of brook trout moving out of the tributaries and neighboring sections makes it impossible to compare the known data (which pertain chiefly to the period after improvement) with previous conditions. However, if Section B has been improved so that its carrying capacity for brook trout has increased as our studies indicate, is the source of the increase of particular importance? It may be logically reasoned that if 10 trout leave Section A to reside in Section B, they have made space and food available for 10 other trout to survive in Section A. Similarly, if one assumes that before improvement of Section B, 90 fish out of every 100 moving downstream out of Tributary 3 continued on downstream in Hunt Creek, whereas after the deflectors were placed only 80 out of 100 migrated out of Section B, then more space and food would be available for the fish populations of the lower waters. Although the total increase of the population in Section B did not originate entirely from within the improved section, it is evident that stream conditions there after improvement are such that the section is now capable of supporting more brook trout. This fact appears to be demonstrated by the general increase in the number and poundage of the different size groups of brook trout taken in the population counts, and also by the increased numbers of legal-sized fish in the anglers' catches.

Natural spawning was observed to occur each fall in Section B throughout the 6-year period of the study. Since there were no counts of nests prior to the installation of the stream-improvement devices, no comparison with the 32 redds observed in the fall of 1944 can be made. In 1944, several redds were noted along the gravelly upstream faces of deflectors, or at their ends where suitable bottom had been exposed by placement of the devices. All available data indicate that natural spawning has continued to be successful. The increases noted in the brook trout population probably result from better survival of young brook trout, a circumstance attributed to the habitat changes made by the deflectors.

Changes in angling.—A comparison of the returns to the angler from a water area before and after environmental improvement is the best measure of its value. Tarzwell (1937) reported angling results on an area of the East Branch of the Black River in Michigan before and after improvement. Although the number of seasons of fishing before and after improvement is not stated, Tarzwell's data indicated a 48-percent increase in angling quality, as measured by the number of trout caught per hour, following improvement.

The same author (Tarzwell, 1938) chose a different method to demonstrate the angling benefits to be derived from stream improvement in experimental work in the Southwest. Two Arizona streams of similar length and physical characteristics were placed under intensive creel census. Horton Creek was improved throughout its length, but Tonto Creek was left unimproved. The creel censuses conducted on these two streams during the 1936 and 1937 trout seasons show that the catch of legal trout per acre on Horton Creek (improved) exceeded that from Tonto Creek (unimproved) by 15 and 48 percent respectively.

Certain features of the Arizona experiment might be questioned, such as the fact that no creel-census data are presented for either Tonto Creek or Horton Creek before Horton Creek was improved. It is unfortunate also that hatchery trout were introduced into these experimental streams during the course of the last season of creel census. Over one-third more legal and near-legal trout were placed in the improved stream than were released in the unimproved water. Although these trout were fin-clipped, Tarzwell stated that the mark regenerated towards the end of the 1937

TABLE 11.—*Summary of intensive creel census for Section B of Hunt Creek for 1939, 1940, and 1941, preceding improvement and 1942, 1943, 1944, 1945, and 1946 following improvement*

[Figures in parentheses show the number of legal-sized brook trout caught and returned to the stream]

Year	Hours of angling	Number of legal brook trout taken	Catch per hour	Pounds of legal fish removed	Pounds per hour	Average size		Percentage of unsuccessful angling days
						Length (inches)	Weight (ounces)	
1939	33.50	15(6)	0.45	1.11	0.033	7.4	2.47	70
1940	86.50	41	0.47	6.69	0.077	8.0	2.84	62
1941	74.75	32	0.43	5.23	0.069	7.7	2.68	64
Average	64.91	29.3(2)	0.45	4.34	0.067	7.8	2.74	64
1942	126.50	65	0.51	11.04	0.087	7.8	2.85	54
1943	73.25	67(1)	0.91	10.96	0.149	7.6	2.70	38
1944	123.50	77(4)	0.62	11.81	0.096	7.6	2.57	43
1945	77.75	36	0.46	7.09	0.091	8.0+	3.00	54
1946	132.25	78	0.59	11.51	0.087	7.5−	2.36	61
Average	106.65	64.6(1)	0.61	10.48	0.098	7.7	2.65	51
Percentage change in average	+64.3	+120.4	+35.5	+141.5	+46.2	−1.2	−3.4	−20.3

season, so that their influence on the 1937 catch could not be evaluated with accuracy. It is not impossible, in view of recovery results noted for plantings of legal-sized hatchery fish in southwestern streams (Gee, 1942), that one-third to one-half of the 1,250 hatchery-reared fish released in Horton Creek in 1937 might have entered the 1937 anglers' catch for that stream.

In the course of the experimental work on the effect of stream-improvement devices on angling quality in Section B of Hunt Creek, an attempt has been made to eliminate experimental practices which might confuse the interpretation of results or impair the validity of the data. The creel-census data for Section B of Hunt Creek are presented in Table 11.

All but two legal-sized brook trout listed in the catches are probably naturally-spawned fish. Plantings of hatchery-reared brook trout fingerlings were made in other areas of Hunt Creek in 1939 and 1940, but in those years all fish released were marked by clipping different combinations of two fins. With the exception of a few experimental plantings of marked legal-sized trout, no fish have been stocked in the Hunt Creek system since 1940. The only possible sources of unmarked legal hatchery fish which might have entered the catches listed for Section B were the fingerling plantings of 1938 or earlier; these fish probably would have been recorded in the 1939 or 1940 catch records (before improvement). In the light of what has been learned concerning the survival of hatchery-reared fingerlings in this stream (unpublished data), it appears doubtful if any but wild brook trout were encountered in those years, but the possibility is not entirely excluded. Two marked legal-sized brook trout of hatchery origin, one of which escaped from an experimental raceway about 400 yards upstream from Section B, and another which migrated upstream about ½ mile from a small experimental planting of legal fish, were taken in the 1942 catch. Except for these two fish all others captured by anglers since the installation of the deflectors have been wild brook trout. The changes in the catch and the angling quality may therefore be regarded as reflecting changes in the natural population of legal-sized brook trout of Section B brought about by the stream improvement.

Creel-census data for the 3 years preceding improvement indicate that there was an average angling pressure of 64.91 hours per season on Section B (range, 33.50 to 86.50 hours). After improvement, angling pressure increased to an average of 106.65 hours (range, 73.25 to 132.25 hours), or a percentage increase of 64.3 (Table 11). Legal brook trout caught in the 1939–1941 period varied between 15 and 32, with an average of 29.3 legal-sized fish per year. After improvement the catch of legal-sized fish ranged between 36 and 78 (average 64.6 fish), or a percentage increase of 120.4 after improvement.

The weight of legal-sized fish removed by angling in the seasons prior to placement of deflectors varied between 1.11 and 6.69 pounds, with an average of 4.34 pounds. After the devices were installed, anglers removed from 7.09 to 11.81 pounds of legal brook trout each season, or an average of 10.48 pounds. The average percentage of increase was 141.5.

It will be noted that, despite the increase in angling pressure on Section B, the quality of the fishing, as measured either by the catch per hour of legal brook trout or more accurately (Shetter, 1944) by the pounds of legal brook trout removed per hour of angling, has improved. The average catch per hour for the five seasons following improvement was 35.5 percent greater than for the three seasons preceding improvement (0.61 legal fish per hour as compared with 0.45 legal fish per hour). Before improvement the average number of pounds of legal-sized brook trout removed per hour of angling was 0.067. After improvement this figure was increased 46.2 percent, to 0.098 pounds per hour.

There occurred a very slight decrease in the average length and average weight of the legal brook trout taken by angling in the two periods. Before placement of the deflectors, the average size of the legal fish was 7.8 inches and 2.74 ounces. In the 5-year period after installation the average size has been 7.7 inches and 2.65 ounces, a decrease in average length and average weight of 1.2 and 3.4 percent respectively.

There has been an encouraging decrease in the number of unsuccessful angling days (angling days in which no legal fish were taken) spent on Section B. In 1939, 1940, and 1941, from 62 to 70 percent (average 64 percent) of the angling days were unsuccessful. In 1942, 1943, 1944, 1945, and 1946, from 38 to 61 percent of the angling days were nonproductive of legal trout (average 51 percent). In other words, the number of unsuccessful angling days has decreased an average of 20.3 percent since the deflectors have been in place.

The question properly may be raised as to the source of the increase in the yield following installation of deflectors. From brook trout fin-clipped in Sections A and C, two legal fish were recovered in 1942 in Section B by angling, whereas 12 were captured by fishermen in other sections. The three recaptures since that season have been made in stream areas other than Section B (Table 12).

Of the tagged brook trout recaptured in Section B that originated in the tributaries (Table 13), one legal fish of the Section B catch in both

TABLE 12.—*Numbers of fin-clipped brook trout recovered as legal fish by angling, with the year and locality of recovery, from the September 1941 markings in Section A and C of Hunt Creek*

Section of recovery	Brook trout fin-clipped in Section A recovered as legal fish			Brook trout fin-clipped in Section C recovered as legal fish			Total recoveries for each section
	1942	1943	1944	1942	1945	1944	
D...	0	0	0	0	0	0	0
C...	1	0	0	6	0	1	8
B...	1	0	0	1	0	0	2
A...	3	1	1	0	0	0	5
Below A...	0	0	0	2	0	0	2
Total	5	1	1	9	0	1	17

TABLE 13.—*Number of tagged brook trout, recovered as legal fish by angling, which originated in Tributaries 3 or 4*

[Where no figure is given, fish from the particular tagging were not available for capture]

Stream where tagged	Time of tagging	Total brook trout tagged moving downstream	Year and section of recovery[1]												Total recoveries for all years by section			
			1942				1943				1944							
			C	B	A	Below A	C	B	A	Below A	C	B	A	Below A	C	B	A	Below A
Tributary 3	Oct. 1941–Sept. 1942	138	0	1	2	2	0	1	0	0	0	0	1	1	0	2	3	3
	Oct. 1942–Sept. 1943	277	0	0	0	0	0	0	4	3	0	0	1	0	0	0	5	3
	Oct. 1943–Sept. 1944	133	. .	. .	. .	. .	0	0	0	0	0	0	4	0	0	0	4	0
Tributary 4	Oct. 1940–Sept. 1941	202	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oct. 1941–Sept. 1942	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oct. 1942–Sept. 1943	209	0	0	0	0	0	0	1	0	2	1	0	0	2	1	1	0
	Oct. 1943–Sept. 1944	182	. .	. .	. .	. .	0	0	0	0	0	1	0	1	0	1	0	1
Totals	. . . .	1,153	0	1	2	2	0	1	5	3	2	2	6	2	2	4	13	7

[1] Four fish recaptured in Fuller Creek not listed

1942 and 1943 came from Tributary 3 or Tributary 4, and in 1944, two legal fish came from Tributary 4. No brook trout tagged moving downstream in Tributary 2 have as yet been recovered by Section B anglers. Twenty-six recoveries have been made in other stream areas from the tagging in the tributaries since 1941. Since October 1941 almost all legal-sized brook trout moving down the tributaries have been tagged, and because about 68 percent of all illegal-sized fish have also been tagged, the unmarked legal trout in the Section B catch may be regarded as originating for the most part from some portion of the main stream. Since there has apparently been only a small amount of movement of brook trout into Section B from Sections A and C it seems logical to assume that the increases noted in the catch in Section B are the result of a greater survival to legal size of young brook trout reared in this part of the stream. A general analysis of the probable origins of the components of the anglers' catch in Section B in the various years since improvement indicates that approximately 96 percent of the anglers' catch originates from within Section B, whereas Section A, Tributaries 3 and 4, and Section C contribute about 4 percent (Table 14).

TABLE 14.—*Marked fish recovered by anglers in Section B, 1942-1946, inclusive*

[Percentages of marked fish in total catch are given in parentheses]

Year	Section of origin of marked fish caught in Section B				Hatchery fish	Presumably from Section B[1]	Total catch of Section B[2]
	Section A	Tributary 3	Tributary 4	Section C			
1942	1 (1.5)	1 (1.5)	0 ...	1 (1.5)	2 (3.0)	60 (92.5)	65 ..
1943	0 ...	1 (1.5)	0 ...	0 ...	0 ...	66 (98.5)	67 ..
1944	0 ...	0 ...	2 (2.6)	0 ...	0 ...	75 (97.4)	77 ..
1945	0 ...	0 ...	1 (2.8)	0 ...	0 ...	35 (97.2)	36 ..
1946	2 (2.6)	1 (1.3	0 ..	0 ..	0 ...	75 (96.1)	78 ..
Totals	3 (0.9)	3 (0.9)	3 (0.9)	1 (0.3)	2 (0.6)	311 (96.4)	323 ..

[1] Unmarked

[2] Marked and unmarked

A comparison of the trends in the angling quality in Sections A and C, as well as in Section B, is also of some interest. The average number of legal-sized brook trout taken in Section A has decreased 14.2 percent since the improvement of Section B, and 28.9 percent in Section C (Table 15). The catch per hour in Section A increased 41.1 percent but decreased 14.3 percent in Section C. Prior to improvement the quality of fishing in Section B was considerably poorer than in Section A and about the same as in Section C. Following improvement the catch per hour in Section B averaged much higher than in Section C but was still less than in Section A. In other words, fishing got better in Section A and poorer

TABLE 15.—*Number of hours fished, number of brook trout caught, and catch per hour in Sections A, B, and C of Hunt Creek before and after installation of deflectors in Section B*

Year	Section A			Section B			Section C		
	Total angling hours	Total trout caught	Catch per hour	Total angling hours	Total trout caught	Catch per hour	Total angling hours	Total trout caught	Catch per hour
1939	199.00	143	0.72	33.50	15	0.45	262.75	112	0.43
1940	296.25	152	0.51	86.50	41	0.47	259.50	113	0.44
1941	315.75	126	0.40	74.75	32	0.43	443.00	180	0.41
Average	270.33	140.3	0.51	64.91	29.3	0.45	321.75	135.0	0.42
1942	189.75	136	0.72	126.50	65	0.51	391.50	117	0.30
1943	162.50	136	0.84	73.25	67	0.91	135.00	90	0.66
1944	151.50	154	1.02	123.50	77	0.62	163.75	62	0.38
1945	124.50	60	0.48	77.75	36	0.46	226.25	102	0.45
1946	203.00	116	0.57	132.25	78	0.59	411.25	109	0.27
Average	166.25	120.4	0.72	106.65	64.6	0.61	265.55	96.0	0.36
Percentage change in averages	−39.5	−14.2	+41.1	+64.3	+120.4	+35.5	−17.5	−28.9	−14.3

in Section C in spite of no environmental improvement until fall of 1945 when 16 deflectors were installed in Section A.

The effect of the war on fishing pressure is evident in the total angling hours recorded for each section. It will be noted, however, that whereas the 5 years following improvement it increased 64.3 percent in B. In the average load decreased 39.5 percent in A and 17.5 percent in C, in the absence of information concerning the relationship between angling quality and angling pressure, the only explanation that can be offered for the percentage increases in average number of legal brook trout caught and average catch per hour following improvement for Section B is an increase in the stock of legal-sized fish available in Section B. If the population of legal brook trout had not increased in Section B after improvement, the percentage increase in angling pressure noted in that section would have resulted in a decline in average angling quality.

Although it might appear that the increases noted for Section B in Table 14 were drawn from Section C, the marking data previously discussed indicate that this influence was small.

Economic Considerations

Assuming that the average difference in the yield to the angler can be attributed to the addition of pool-forming structures one can calculate the cost of adding one brook trout to the catch. Installation and maintenance for the 5-year period has cost to date $512.16. The average difference in the number of brook trout caught and kept by anglers in the period before as compared with the period after improvement was 36.3, or a total of 181.5 for the 5 years. Hence there was an actual cost of $2.82 for each additional brook trout entering the catch during the entire period after improvement.

Properly maintained, the deflectors should function for at least 20 years. Maintenance costs have decreased as the structures have become stabilized by the compacting of fill materials and by deposition of sediments behind the structure. Assuming, however, that the annual cost of maintenance will remain at $26 for the 20-year period and that the average annual contribution to the catch of trout will remain at 36.3, the estimated cost per additional trout produced during the 20-year period would be $1.24.

In the light of our present knowledge of conditions on Section B it seems possible that a similar increase in yield might have been attained by using fewer structures more skillfully placed. As will be noted from Figure 1, some deflectors produced larger and deeper pools than did others. Although individual records were not kept for each pool it was noted that some yielded more legal brook trout than others, and population studies have shown that some pools contained larger numbers of legal-sized fish than did others.

Whether the cost figures for Hunt Creek would be directly applicable to other waters of the state is questionable, but they constitute the first reliable estimate of the expense involved in producing additional trout for the angler by stream improvement. Admittedly it is expensive, but perhaps not more so than planting legal-sized fish if all proper charges and the actual returns to the angler are considered; furthermore the results are not open to the same serious objections that apply to planting. Additional experiments are under way in other sections of Hunt Creek and similar investigations are contemplated for streams elsewhere in the state on which accurate data on yield can be obtained.

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Acknowledgment of field assistance is made to Paul Barrett, Lawrence Bush, and Edwin Cooper, and to the various creel-census clerks employed seasonally at the Hunt Creek Experiment Station. The Station's first director, Dr. Justin W. Leonard, participated in the initial phases of the study, and since his return from military service has critically read the manuscript and offered numerous suggestions incorporated herein.

SUMMARY AND CONCLUSIONS

Data obtained by mapping, population, and food studies, and by an intensive creel census for a 3-year period before and a 5-year period after the installation of 24 pool-forming deflectors in a 1,605-foot section of Hunt Creek, Montmorency County, Michigan, may be summarized as follows:

(1) The number of pools judged to be capable of supporting legal-sized trout rose from 9 to 29.

(2) The average pool depth was increased by approximately 6 inches.

(3) Additional gravel was exposed by local current acceleration, and shifting sand and silt were stabilized adjacent to the structures.

(4) No significant change in total stream area or in average depth in the entire stream section was apparent. Bottom scouring and deposition are therefore considered to be local and compensatory.

(5) Preliminary studies of the bottom food supply indicated a decrease in the total number and volume of all organisms but an increase in the forms found most frequently in stomachs of trout from the stream.

(6) Fish population studies made by the block-and-seine method and by the use of the electric shocker in five sample areas demonstrated a slight increase in the number of brook trout of all size groups, a small decrease in the average size of fingerling and illegal brook trout, an increase of muddlers and minnows, and a decline in the number of crayfish.

(7) Averaging the creel census figures for the 3-year period before and the 5-year period after improvement showed increases in the anglers' catch after improvement of 120 percent in total number and 141 percent in total pounds of legal trout, and 35 percent in number and 46 percent in pounds per fisherman-hour, in spite of a 64 percent increase in fishing pressure. Average size of the trout caught decreased 1.2 percent in

length and 3.4 percent in weight. The percentage of unsuccessful anglers decreased 20.3 percent.

(8) That increase in trout population and yield (as shown by census of the anglers' catch) was due mainly to a greater survival of young trout produced in Section B, and not to migration to this section from tributary streams or from the stream above or below the experimental area, was demonstrated by the recovery in Section B, by seining or by creel census, of few fish which had been marked descending through weirs on the tributaries or in the sections on either side.

(9) Comparison of creel census figures for the sections of stream immediately above and below the experimental area failed to show improvement in quality of fishing and size of yield similar to that of Section B during the period after installation of the deflectors.

(10) The improvement in trout fishing in Section B of Hunt Creek is due to beneficial changes in the physical and biological environment wrought by current deflectors.

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COOPERATIVE FISHERY SURVEY OF THE UPPER MISSISSIPPI RIVER

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ABSTRACT

Representatives from the States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin and from the United States Fish and Wildlife Service, meeting in December 1943, formed the Upper Mississippi River Conservation Committee for the purpose of carrying on scientific investigations of the fishery and wildlife resources of the Mississippi River from Caruthersville, Missouri, to Hastings, Minnesota. Although originally planned as a post-war project, field operations were started in the spring of 1944. Field work was divided between two units, one operating from Dubuque, Iowa, northward and one operating from Dubuque southward. Status of the fish population was determined by test-netting, and condition of the commercial and sport fisheries was checked by commercial fishing reports, contacts with commercial fishermen, and creel census. Results of preliminary studies indicate that several types of regulations will be needed in different areas because of different ecological and economic conditions.

The Mississippi River between Hastings, Minnesota, and Caruthersville, Missouri, constitutes one of the more important inland waterways and fresh-water commercial fishing areas in the country. This section of the river also affords some of the finest sport fishing and hunting in the Mississippi Valley. The problem of managing the fishery resources of the stream and adjacent waters has been left to the legislatures and the conservation agencies of the several states involved, whereas management of game and furbearers has been shared by the states and the United States Fish and Wildlife Service. In some areas there are now two sets of regulations, each effective to mid-channel, and in others, uniformity between states has been achieved by reciprocal agreement. Frequently, abrupt and arbitrary changes in restrictions which are unsupported by biological or economic fact occur at state lines. The fact that manipulation of the navigation dams in the canalized portion of the river has been carried on with little consideration of possible effects on the wildlife and fishes further complicates the problem. Under such conditions, the most efficient use of sport and commercial fisheries has been impossible.

Conservation administrators of the upper river states at a meeting of the Midwest Game and Fish Commissioners in 1943 discussed ways and means to secure uniformity of regulations governing exploitation of the fish, game, and fur animals and to promote a program of effective management for the river which would give due consideration to all economic and recreational interests. It was immediately apparent that the greatest obstacle to any plan of unified action was the practical absence of accurate data concerning the fish species and the factors controlling their abundance and use. In order that an effective plan for obtaining the necessary information might be initiated, the five upper-river states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin) and the Fish and Wildlife Service sent representatives to a conference held at Dubuque, Iowa, on December 15, 1943. At this meeting the Upper Mississippi River Conservation Committee was formed by a unanimously adopted resolution which, among other organizational directives, made the following statement of the objectives, membership, and duties of the Committee:

> In order to provide for the carrying on of cooperative surveys and studies of conditions of national and interstate concern affecting conservation, wildlife, and the recreational interests in the upper Mississippi River, the following plan of organization and operation is agreed upon between the conservation agencies of the states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin and the United States Fish and Wildlife Service.
>
> The project shall be in general charge of a committee to be known as the Upper Mississippi River Conservation Committee to be composed of not to exceed three representatives from each of the five participating states and the United States Fish and Wildlife Service, to be designated by the Conservation and Public Health authorities of the states respectively, and the Director of the United States Fish and Wildlife Service. . . .
>
> The Committee shall formulate plans, policies, and programs for carrying on the cooperative surveys, their studies for the above-stated purposes, for the keeping of necessary records, and the preparation, publication, and distribution of necessary reports and for providing personnel, equipment, and funds for such purposes by the participating agencies, subject to such approval as may be necessary to give effect thereto by the proper authorities of such agencies and shall make such recommendations in furtherance of the objects of this organization as it may deem proper from time to time.

The investigations sponsored by the committee were planned originally for post-war execution, but war-time exploitation of the commercial fishery and the serious dislocation of the wildlife habitat occasioned by unprecedented water-level fluctuations during winter in the navigation pools caused the initiation of projects with a skeleton staff in the spring of 1944.

Two technical sub-committees, one on fisheries and one on game and fur-bearers, were given the responsibility of making plans and carrying out the details of the various studies. The sub-committee on fisheries began work immediately but the work of the game sub-committee was not started until the close of the war. To permit effective administration, the fishery investigations were divided into two geographical units, each under the charge of a senior biologist who was responsible to the technical sub-committee for uniformity of scientific procedure and the interpretation of results. The northern unit was to study the river between St. Paul and Dubuque and the southern unit between Dubuque and Caruthersville, Missouri.

The most pressing problems confronting the sub-committee were to determine: (1) the status of the fish population in all river areas, with special reference to abundance, rate of growth, size distribution, and the effectiveness of natural reproduction in all species; (2) the degree and nature of commercial exploitation of the various fishes; (3) the relative importance of the sport and commercial fisheries; (4) the influence of existing regulations on fish populations; (5) the efficiency and destructiveness of the various commercial gears; and (6) the effects of water-level fluctuations in the canalized portion of the river, and of siltation and pollution on fish and mussel production. The sub-committee faced the further problem of preparing recommendations for management procedures and regulations which would insure the greatest sustained production of desirable fishes. These problems have been attacked in various ways according to their nature and the available facilities. Basic questions concerning the nature of fish populations have been approached through the medium of test-netting and careful observation of commercial fishing operations. During 1944 the southern unit used the Illinois Natural History Survey's laboratory boat, *Anax,* as a base for test-netting operations in the lower portion of the southern area. All habitats were checked and fish samples secured for determination of size-frequency distribution and other life-history data. In 1946, after a lapse of a year, the work of this unit was resumed and similar test-netting operations were undertaken on the upper portion of the southern section of the river.

To determine the nature of the commercial fishery, efficient methods of gathering fishery statistics were recommended to the various states. A majority of the 2,330 commercial fishermen licensed in 1944 were contacted to check methods of operation, uses of various types of gear, economic factors governing fishing, and similar information pertinent to the fishery. In the river above Dubuque, where sport fishing is most important, a creel census covering both winter and summer angling seasons contacted a group of fishermen representing a combined effort in excess of 125,000 hours of angling.

Observers have been placed in fish markets to collect information on the size frequency of fish in the commercial catch, to secure scale samples for determinations of age and rate of growth, and to measure size and weight at maturity of the various commercial species. In addition, biologists work with commercial fishermen during regular fishing operations.

In order to evaluate the effects of drawdowns on the wildlife habitat winter investigations of the navigation pools have been made with the assistance of the United States Army Engineer Corps. Water quality and pollution studies by the water-pollution laboratory of the United States Fish and Wildlife Service have been made. Special life-history studies, especially pertaining to the catfishes which include some of the most important commercial species of the river, have been carried on concurrently with the activities already described.

Since full-scale operation of the survey over the entire area has been in progress only during the 1946 field season, it is too early to present mature results or to make any comprehensive and final recommendations for management of the fishery and other wildlife resources. Summaries of biological data and tentative recommendations have been presented in two progress reports.[1] Several broad concepts are beginning to take shape. One of the more obvious conclusions is that uniform regulations from north to south cannot be made to cover all phases of the fishery. Many special regulations must be applied on the basis of natural ecological areas rather than state boundaries because the upper river presents neither a uniform habitat nor a homogeneous fishery. In the northern section sport fishing as well as commercial fishing is highly important, whereas in the greater part of the southern section the principal interest is the commercial fishery. It is clear also from the preliminary studies that regardless of the several states involved, regulations on any section of the river must be uniform if the fish populations are to be managed on a biologically sound basis.

The principal significance of the Upper Mississippi River Survey from an administrative standpoint is that it represents a cooperative effort of six separate conservation agencies to secure the biological data necessary for the solution of a common problem on 900 miles of river. No funds other than a nominal fee for secretarial services are contributed to the central organization. Instead, the necessary biologists, specialists, and assistants, together with the equipment required to make the various investigations, have been supplied by the states and the Fish and Wildlife Service to be utilized under a common leadership for the various projects. The results of the scientific research will be contained in a series of bulletins edited and published by the Committee.

While fiscal and administrative phases of a loose cooperative set-up are likely to be clumsy and lacking in efficiency, the diligent guidance of the Committee has succeeded to date in utilizing the diverse resources to effect a unified program of scientific investigation under the leadership of competent biologists. Such a cooperative effort, by agencies frequently at variance over the methods of managing a fishery in boundary waters, indicates that conservation administrators realize that comprehensive and thorough research is the only possible basis for the solution of fishery problems. The success already achieved in the present project leads to the conclusion that other difficult fishery and wildlife problems can be attacked in a similar manner.

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[1] Preliminary Progress Report, Upper Mississippi River Conservation Survey Committee, April 23, 1945, 17 pp. (Mimeographed) ; and Second Progress Report of the Technical Committee for Fisheries, Upper Mississippi River Conservation Survey Committee, January 28, 1946, 27 pp. (Mimeographed).

A DEFINITION OF DEPLETION OF FISH STOCKS

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Abstract

Attention was focused on the need of a common and better understanding of the term depletion as applied to the fisheries in order to eliminate if possible the existing inexactness of thought on the subject. Depletion has been confused at various times with at least ten different ideas associated with it but which, as has been pointed out, are not synonymous at all. In defining depletion we must recognize that the term represents a condition and must not be confounded with the cause (overfishing) that leads to this condition or with the symptoms that identify it. Depletion was defined as a reduction, through overfishing, in the level of abundance of the exploitable segment of a stock that prevents the realization of the maximum productive capacity.

The question of depletion has assumed paramount importance in the discussions of many of our fishery investigators today. I may refer to the recent publications of E. S. Russell of England, of A. G. Huntsman of Canada, of G. L. Kesteven of Australia, and of W. F. Thompson, W. C. Herrington, Elmer Higgins, David Thompson, R. W. Eschmeyer, W. E. Ricker, T. H. Langlois, and A. S. Hazzard of the United States, to mention but a few.

The current outburst of such papers in the United States is in large measure one of the byproducts of the recent extensive investigations on inland lakes and impounded waters and on the productivity of artificial ponds. These widely publicized studies have stressed the high inherent capacities of waters to produce fish and the general failure to utilize fully the fish crops, and as a result there developed the "underfishing" theory. This theory led to recommendations to reduce or remove restrictions on fishing.

From the "underfishing" theory it was not too difficult to develop the concept that depletion and overfishing are illusory and unreal. Huntsman (1943), for example, wrote, " 'Depletion', except as an uneconomic condition which may exist when fishing starts, is little more than a bogie to frighten the credulous." Langlois (1944) penned these words, "The cry of 'overfishing' is a bugaboo which is seldom or very rarely justifiable." However, Huntsman's concept of depletion "as an uneconomic condition" seems to be at variance with the most common understanding among scientists. According to this quoted statement we should hold, for example, the untenable position that the yellow perch of Lake Superior, which never could be fished economically because of its scarcity, was depleted when it was first taken nearly 100 years ago. On the other hand, neither could the so-called trash fish be produced economically at that time even though they in contrast to the Superior perch were plentiful. It is true, depletion ordinarily leads to an uneconomic condition, but these two certainly are not the same; they are cause and effect. Uneconomic conditions may also arise without depletion (see item 3).

In reading current literature on fishing, it becomes evident that some fishery workers as well as the general public have no clear conception as to what actually constitutes depletion. As a rule the term depletion is employed or interpreted very loosely—it means different things to different people. Perhaps most people think of it in terms of DeQuincey's definition of fishing—"an unceasing expectation and a perpetual disappointment." Commercial fishermen often judge the success or failure of fishing by the size of their bank balance at the end of a year, and sport fishermen commonly use the degree of their satisfaction with fishing as a criterion of depletion. As already indicated above, scientists likewise disagree. They have defined depletion variously as a declining yield per unit of effort, as a lack of balance between mortality and replacement or between outgo and income, as a reduction in the level of annual yields expressed in terms of pounds below the largest possible, as a reduction by fishing in numbers of fish below the point of profitable operation, or simply as the uneconomic utilization of the supply when the fishery fails to take advantage of the growth rates of the fishes and an intensive fishery produces no greater yield in pounds than a less intensive one.

The various concepts of depletion may be merely a matter of definitions or a failure to differentiate carefully between depletion and the phenomena that are often associated with it. Be that as it may, unless we have a common understanding we shall always be at loggerheads with one another as to whether depletion exists in any body of water. I believe that it is worth while, therefore, to analyze the subject in detail and attempt to clarify our thinking on it. Perhaps the best approach is to point out first what depletion "is not" and then on this basis propose a simple but precise definition that may be acceptable to all interested parties. The various items are discussed under 13 subheadings, and, to conserve space, each is touched upon very briefly and pointedly.

1. *Depletion and a low capacity to produce fish are not synonymous.*—A body of water that is producing to full capacity can hardly be considered depleted when its small stock of fish is the result solely of unfavorable living conditions irrespective of whether these were produced by natural forces or by man. Such waters should simply be designated as poor lakes, poor reservoirs, poor streams, . . . Even they may be subject to depletion.

2. *Depletion and natural fluctuations in abundance are not synonymous.*—These two are often confused even by scientists. A low level in the natural cycle of abundance is not depletion. Natural fluctuations occur

under primeval conditions in virgin waters as well as under conditions of severe depletion, and result from natural factors of abundance. It is difficult to discriminate between natural fluctuations in abundance and variations due to fishing intensity without an analysis of year-class composition. This statement is particularly true when fish are fairly plentiful. However, when abundance is severely reduced and fishing intensity is very low, noticeable changes in yield usually may be attributed to natural factors. For example, when the United States production of the Lake Erie cisco averaged nearly 20 million pounds per year during the period, 1885–1924, and fluctuated from 8 1/3 million to more than 39 million pounds, fishing intensity which varied considerably during this period played an important role in these fluctuations even though its influence may have been masked to a certain extent by natural changes in abundance. However, when in the years, 1925–1945, the annual yield averaged only 629,000 pounds or 3.2 percent of normal and fishing intensity for the cisco was at a very low level, the fluctuations in take (25,000 to 2,817,000 pounds) were largely the result of natural factors. This statement is supported by the recent temporary return of ciscoes in 1945 and 1946 which was due entirely to the unexplained large survival of the 1944 year class that comprised 98 percent of the catch in each of these two years. With the passing of this year class, however, cisco fishing will again revert to the low level of production characteristic of recent decades. Incidentally it may be observed here that a high level in a cycle of natural abundance can deceive us as well as a low level.

3. *Depletion and unsatisfactory fishing are not synonymous.*—Fishermen, particularly sportsmen, often assume that unsatisfactory fishing is indicative of depletion. Such a conclusion may or may not be justified. Many investigations with experimental nets on inland lakes and reservoirs have shown that, although fishing with hook and line was reported to be poor, these waters nevertheless contained a large population of adult fish. Such unsuccessful fishing may be due to many factors as: dense vegetation, a superabundance of natural fish food, a seasonal shift in the distribution of fish, dwarfing, sluggishness, or perhaps simply a "cussedness" on the part of the fish. Deterioration of fishing with efficient commercial gear may as a rule be accepted as indicative of a decline in the stock, and persistent poor fishing on a stream or very small lake likewise may be suggestive of such a reduction. However, earnings are not a safe criterion by which to judge the status of a fishery, since they may vary with factors other than abundance of fish such as: price of fish, cost of operations, and skill or knowledge of fishermen.

4. *Depletion and uneconomic utilization are not synonymous.*—Uneconomic utilization of the fish supply means "the catching of fish too soon; catching fish when they are too small and frequently before they reach maturity" (Higgins, 1941). In this situation the fishery fails to take full advantage of the growth rates of fishes and as a result "An intensive fishery . . . takes no more fish in the end than a much less intensive

fishery. . . . " (Higgins, 1941). This uneconomic exploitation, however, is a type of overfishing which leads to depletion and is not to be confused with depletion itself (see p. 288).

A word of caution should be interpolated here against the danger of confusing depletion as a biological phenomenon with the problem of obtaining the greatest possible financial returns. To illustrate this point, in some situations the most profitable fishing is to be had at a level of production below the maximum possible yield. From a monetary standpoint, for example, 4 million pounds of fish that bring 15 cents per pound are more valuable than 5 million pounds of a less desirable market size that will bring ony 10 cents per pound.

5. *Depletion and a reduction in numbers of fish are not synonymous.*—Reduction occurs as soon as fish are removed from the water by fishing or any other means. Depletion always involves a reduction in numbers, but the reverse is not true.

6. *Depletion and a reduced total yield are not synonymous.*—Yields vary not only with the abundance of the fish but also with such factors as fishing intensity which in turn depends on human, economic, and environmental forces. A decline in real abundance may be masked by figures of constant or even increased yields resulting from greater or expanded fishing intensity, fishing efficiency, or changes in habits of fish or in regulations. Depletion always involves reduced yields, but the reverse is not true.

7. *Depletion and a scarcity of exploitable fish are not synonymous.*—The proper exploitation of a fishery calls for the capture and use of all of the exploitable surplus. Under ordinary circumstances the removal of fish takes place continuously over a period of time. Should the physical conditions of the fishery, however, permit the taking of all surplus fish of the optimum size at one time or within a short period, no fish would be available for capture until recruitments replenished this stock. Yet depletion would not be involved during this period of scarcity, since the reduction of the abundance of exploitable fish to the minimum essential to reproduction is not interfering with the total yield—the entire surplus but only the surplus has been removed. The complete short-term cropping affects only the distribution of that production with respect to time. Such a condition of temporary scarcity is often erroneously referred to by sportsmen as depletion.

8. *Depletion and a declining yield per unit of effort are not synonymous.*—The catch per unit of fishing effort may decrease as the result of an increase in the total fishing effort or quantity of gear used rather than a decline in the abundance of the fish. Obviously 1 net used on a school of 10,000 fish will take more per lift than 10 nets. A declining yield may, however, be a symptom of depletion (see p. 288).

9. *Depletion and a reduction in the stock through factors other than fishing are not synonymous.*—If such factors as pollution, dams, dredging, silting, storms, "winterkill," epidemics, predators, competitors, . . . are

considered agents in depletion, then depletion becomes synonymous with capacity to produce (see item 1) and with a low level in the cycle of natural abundance (see item 2), which conclusions perhaps none of us wants to accept. Pollution, dams, dredging, . . . change basic capacities, either decreasing or increasing them, and low levels in a natural cycle may be due to predators, storms, etc., destroying the eggs, larvae, or young fish. Unless we restrict the factor of depletion solely to fishing, we are certain to encounter inconsistencies in our thinking and run into other difficulties. We could hardly designate as depletion the crowding out of the finer fishes in lakes and streams by excessively dominant competitive groups such as carp, or the decimation of lake trout in Lake Huron by sea lampreys, or the recent heavy destruction of the Great Lakes smelt by some epidemic disease.

10. *Depletion and extermination are not synonymous.*—If these two conditions are identical, then depletion by fishing is virtually impossible, since methods currently employed do not take every fish. Furthermore, fishing for a species ceases long before it approaches the point of extermination. Species have disappeared from waters, and fishing may have been a contributing factor in that it reduced the level of abundance to the point where the stock became vulnerable to unfavorable conditions that would not have exterminated the population at a greater density. In these situations, however, the actual extinctions were the results of factors other than fishing. Even such a heavily persecuted and highly vulnerable species as the sturgeon has not been exterminated in the Great Lakes by fishing, although its numbers have been severely reduced.

11. *Depletion can exist in the face of perfect balance between recruitment and yield.*—Obviously a continued state of inequality between income and outgo must lead to depletion if the latter exceeds the former. On the other hand, a state of perfect balance may exist at any level of abundance—in a virgin stock, in a stock of optimum abundance, and in a depleted stock. In other words, a stabilized fishery may exist at any level of abundance, even one that has approached commercial extinction.

12. *Depletion varies in degrees of severity.*—Depletion may be slight or severe, gradual or rapid, short-termed or long-termed. Depletion may affect the entire body of water or only a section of it. The lake trout of Lake Michigan may illustrate a typical long-term or gradual decline. Over a 45-year period (1893–1938) the average annual catch fell progressively from 8¼ million pounds to 7 1/3 million to 5½ million to 5 million pounds. This gradual reduction in take occurred in the face of greatly increased fishing intensity and expanded operations.

13. *What is depletion?*—I hope that it has been made clear that depletion is not synonymous with (1) a low capacity of waters to produce fish, (2) natural fluctuations in abundance, (3) unsatisfactory fishing, (4) uneconomic utilization, (5) a reduction in numbers of fish, (6) a reduced total yield, (7) a scarcity of exploitable fish, (8) a declining yield per unit of effort, (9) a reduction in the stock through factors

other than fishing, and (10) extermination. It was also pointed out that depletion can exist in the face of a perfect balance between recruitment and yield and that it varies in degrees of severity and extent.

It is apparent that depletion is not easy to define and is even more difficult to detect. In drawing up our definition we must differentiate depletion, its cause, and its symptoms. Such discrimination has not always been made. Depletion is a condition. Keeping in mind the various items listed above, we may define depletion as a reduction, through overfishing, in the level of abundance of the exploitable segment of a stock that prevents the realization of the maximum productive capacity. Overfishing is a fishing rate that produces depletion; it is the only causative factor in depletion. The symptoms of depletion are fairly well known. They include such items as a decline in yield per unit of fishing effort, downward trend in total yield in the face of constant or increased fishing pressure, highly erratic production, reduction in the average size and age of the fishes, and increase in their rate of growth. Depletion may develop by overfishing the breeding stock or the unexploitable young fishes or the exploitable fishes that have not quite reached the desirable sizes to provide maximum yield (uneconomic utilization).

Finally, I want to stress one more point. In discussing depletion it is essential that we discriminate between catch by number and by weight. Weight is the basic unit, since productivity represents the conversion of fish food into fish flesh and the quantity of this end product is determined from weight. The population of a lake may be maintaining itself numerically and yet be overfished if the fishing pressure on the larger individuals is so great as to keep down the total yield below the carrying capacity of the waters. Such a situation actually occurred in Onized Lake, Illinois (Bennett, 1945).

In this paper I have attempted to focus attention to the need of a common and better understanding of the term depletion as applied to the fisheries in order to eliminate if possible the existing confusion of thought on the subject and have proposed a precise definition for adoption by fishery workers. Some may object to the restricted definition that attributes depletion solely to overfishing. However, unless we so limit the factor of depletion we cannot readily maintain consistency in our thinking as was indicated in item 9. If a stock is found to have been reduced by unfavorable conditions caused either by natural forces or by man (pollution, competitors, disease, . . .), we should refer to this situation as simply a reduction in abundance and not call it depletion.

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THE STATISTICAAL ANALYSIS OF CREEL-CENSUS DATA

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Abstract

An analysis of the yield of brook trout (*Salvelinus fontinalis*) and rainbow trout (*Salmo gairdnerii*) per unit of fishing effort at Furnace Brook, Vermont, shows how modern statistical methods can be utilized to determine the significance of changes in the relative abundance of animal populations. The data cover the 5 years from 1936 to 1940 and the analysis of covariance employed shows that there was a significant decrease in the catch per unit of effort in 1939 which was attributed to the effects of severe floods caused by the hurricane in September of the previous year. This method of analysis, although useful for supplying a measure of relative abundance, fails to provide an estimate of the actual stock on hand.

A method of estimating the total population based on the proportion of fish maturing and the number of mature fish counted in the spawning run is presented.

A new method for estimating the size of animal populations from data on catch and effort has recently been developed by DeLury. When certain assumptions are made, the following relations hold:

$$\log C(t) = \log (kN(O)) - kE(t),$$

where $C(t)$ is the catch per unit of effort for a given time interval (t),
$E(t)$ is the total effort expended during the time interval (O, t),
$N(O)$ is the number of individuals at $t = O$,
and, k is a constant describing the rate at which the catch per unit of effort decreases as the effort accumulates.

The writer has developed a similar method, which would be much easier for biologists to use, based on the following equation:

$$C(t) = kN(O) - kK(t),$$

where $K(t)$ is the total catch accumulated during the time interval (O, t),
and k is a constant describing the rate at which the catch per unit of effort decreases as the *catch* accumulates.

Data from the rainbow trout fishery at Paul Lake, British Columbia, obtained in 1932, show that both methods of estimation yield approximately the same result. The second method is suggested as an aid for fishery managers who wish to determine the size of their fish stocks. It requires that records be obtained concerning the catch and the fishing effort throughout the fishing season and that the proportion of the different age groups in the catch be determined. If sampling is used, then representative sampling methods are required. An example is given to show how the method may be used by fishery managers.

Introduction

During the past 30 years or more biologists have developed methods which are being used to determine the relative abundance of animal populations. Fishery biologists, for instance, use the data on the number of fish caught per unit of effort to determine whether a given population is increasing or decreasing. The information is also useful for comparing the effectiveness of different management or stocking policies. Not all biologists, however, have a clear-cut idea as to how such data are to be analyzed after they have been collected. Since the intended analysis usually determines what observations must be made in the field, it seems desirable to review recent developments in the methods of analyzing the data on fish populations.

THE ANALYSIS OF RELATIVE ABUNDANCE

The following example will serve as an illustration of the current use of creel-census data in which modern statistical methods may be employed.

Lord (1946) has described the method of collecting creel-census data from the Vermont test waters. The original data were available to the writer for analysis. The yield of brook trout and rainbow trout per unit of fishing effort from the test area of Furnace Brook, Vermont, showed an apparent decline from 1936 to 1940. Certain data for the 5 years are summarized in Table 1. The average yield per unit of effort based on the number of hours expended by the anglers was 1.76 fish per fisherman-hour; the yield for the 3 years 1936, 1937, and 1938 was above this average and the yield for 1939 and 1940 was below it. Since the heavy flood which followed the hurricane of September 1938 may have reduced the trout population of the test area, it becomes a matter of some importance to determine if the differences in yield per unit of fishing effort before and after the flood are significant. If the differences are significant, then it may be inferred that a change has taken place in the size of the population.

TABLE 1.—*Total number of brook trout and rainbow trout caught* (Y) *and the total number of hours expended* (X) *by the anglers at Furnace Brook, Vermont, for the 5 years 1936 to 1940, together with the average catch per fisherman-hour*

Year	Number of hours *(X)*	Number of fish *(Y)*	Fish per fisherman-hour
1936	3,550	6,995	1.97
1937	3,544	6,385	1.80
1938	2,551	4,647	1.82
1939	2,103	2,997	1.42
1940	2,469	4,063	1.64
5 years	14,217	25,087	1.76

A rather extensive background investigation revealed that the standard design for an analysis of covariance may be used to conduct the test, provided that the original data are transformed to square-roots.

In order to provide a measure of the variability within the different years the original data were combined into 16 periods consisting of the first day and the rest of the season divided into fifteen 7-day periods.

The analysis of covariance, the errors of estimate, and the test of significance are shown in Table 2. The *F*-value 4.045 is highly significant, indicating that there are significant differences among the mean yields for the different years, after adjustments have been made for the differences in effort.

TABLE 2.—*Analysis of covariance, errors of estimate, test of significance, and regression of the yield of brook trout and rainbow trout from Furnace Brook, Vermont, for the 5 years from 1936 to 1940*

[X and Y are the square roots of the number of hours expended and the yield, respectively]

Analysis of covariance

Source of variation	Degrees of freedom	Sums of squares and products		
		Σx^2	Σxy	Σy^2
Total	79	1608.52	1951.78	2808.19
Between-years ..	4	148.90	275.11	521.21
Within-years ...	75	1459.62	1676.67	2286.98

Errors of estimate

Source of variation	Degrees of freedom	$\Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2}$	Mean square
Total	78	439.90	
Within-years ...	74	360.98	4.878
For test of significance ..	4	78.92	[1]19.73

Test of significanse ....$F = \frac{19.73}{4.878} = 4.045$; $n_1 = 4$; $n_2 = 74$

Regression ....$Y = 2.263 + 1.149x$

[1] Highly significant

The conclusions seems warranted that there was a significant change in the yield of trout per unit of fishing effort in the test area of Furnace Brook, Vermont. The yield was above expectation in 1936 and significantly below expectation in 1939. The sudden drop in 1939 might reasonably be ascribed to the effect of the flood which occurred in September 1938. The yield in 1940, although below expectation, was not significantly low which fact seems to indicate a certain amount of recovery.

This example indicates that the stock in the stream was reduced in 1939 but it gives no indication of the magnitude of that change in terms of the number of individuals. Such information would be much more useful to the fishery manager if he knew exactly how many fish he had on hand at any particular time. Any management practice that the manager may adopt is conditioned by his estimate of the stock on hand.

For example, the number of fish to be carried over from one season to the next should be gauged according to the food supply in order to permit sufficient growth and to conserve the breeding stocks of food animals.

ESTIMATION OF POPULATION

In an effort to get at the question of estimating the total stock on hand, biologists have used tagging, marking, or banding methods. If the number of tagged individuals at large in the population is known, it is possible to estimate the total stock from the proportions of tagged individuals in the catch. Schnabel (1938), Underhill (1939), and Schumacher and Eschmeyer (1943) gave examples of the use of the method.

The writer has employed the method in a way which may prove to be useful in certain situations. If a fairly complete count or estimate can be made of the spawning component of a trout population then it is possible to compute the total population from data on the proportion of maturing fish in each age group. An example is given in Table 3 based on data obtained at Paul Lake, British Columbia, in 1932 and 1933. The proportion of fish maturing was obtained by examining 445 fish caught by anglers during August and September 1932. At that time the enlargement of the gonads was used as a criterion for deciding which fish were maturing. This criterion served, therefore, as a natural mark. The age of the fish was determined by scale reading. The total population of 2-year and older fish at the beginning of the fishing season (May 1) was estimated with an accuracy of one significant figure to be about 5,000 fish consisting of about 4,000 immature and 1,000 mature fish. The use of such estimates in fishery management is described by Haig-Brown (1947) in his chapter on Paul Lake.

Recently a new approach has been made to the problem of estimating the size of animal populations. In 1946 the writer renewed interest in the problem and began experimenting with the adaptation of a graphic technique for describing the growth of animals that Walford had developed (1946). Several people ,including Prof. R. A. Fisher, Dr. D. B. DeLury, Dr. C. P. Winsor, Miss Marion Sandomire, and others, contributed suggestions which served to refine the idea. Meanwhile, DeLury (1947) working independently, had developed a mathematical formulation for the estimation of biological populations using the relation between catch per unit of effort and *effort*. His equation is as follows:

$$\log C(t) = \log\ (kN(O)) - kE(t), \tag{1}$$

where $C(t)$ is the catch per unit of effort for a given time interval t,
$E(t)$ is the total effort expended during the time interval (O, t),
$N(O)$ is the number of individuals at $t = O$,
and k is a constant describing the rate at which the catch per unit of effort decreases as the *effort* accumulates.

The relation between catch and catch per unit of effort that the writer

TABLE 3.—*Proportion of maturing male and female rainbow trout in several year classes at Paul Lake, the number estimated in the spawning component of the population in 1933, and the estimate of the number of legal-sized fish in the population as derived from the data*

Year classes[1]	Males				Females				Total population
	Proportion maturing	Estimated number spawning	Estimated number of immature fish	Total number of males	Proportion maturing	Estimated number spawning	Estimated number of immature fish	Total number of females	
1931	0.25	500	1,500	2,000	0.01	10	[2]1,990	2,000	4,000
1930	0.60	100	70	170	0.50	150	150	300	470
1929	0.75	30	10	40	0.80	100	20	120	160
Older	1.00	20	–	20	1.00	90	–	90	110
Totals	. . .	650	1,580	2,230	. . .	350	2,160	2,510	4,740

[1] Members of year-class 1932 below legal size and not available to the fishery

[2] This estimate is based on a 50-50 sex ratio in the year-class

developed has also been investigated by DeLury (1947), who expressed it by the following equation:

$$C(t) = kN(O) - kK(t), \tag{2}$$

where $K(t)$ is the total catch accumulated during the time interval (O, t),

and k is a constant describing the rate at which the catch per unit of effort decreases as the *catch* accumulates.

An attempt was made to use these methods for estimating the size of the Furnace Brook population, but it became evident in the course of the investigation that, since recruitment was taking place throughout the season, it was impossible without data on the age of the fish to disentangle the components of depletion and recruitment. A similar effort was made to estimate the size of a known population of marked rainbow trout in North Creek, Virginia, (Surber, 1947) but some factor, possibly temperature, or unaccounted-for-mortality, or emigration, caused a change in the catchability. The estimation of the stock on hand in streams is evidently a much more difficult task.

In order to illustrate the use of the two equations, creel-census data on rainbow trout obtained at Paul Lake, British Columbia, in 1932 were selected (Mottley, 1940). About 70 to 80 percent of the fish are caught by anglers using boats from a single boat livery. The proprietor of the boat livery kept records of the number of fish caught per boat each day throughout the fishing season. Samples of the fish were selected from time to time, from which scales for age determinations were taken. It was thus possible to divide the population into two parts: the yearlings, some of which begin to reach legal size in July, and which steadily increase in the catch until October; and the fish 2 years old and older which are completely available to the fishery from May 1 to October 31. The latter group is thus exposed to depletion at all times during the 26-week fishing season. The data for 1932 compiled on a 7-day basis showing the number of boat-days as a measure of the effort, and the number of fish caught in the group 2 years old and older are shown in Table 4. The values necessary for the estimation from the primary data are also given.

Fitting these data by least squares, equation (1) now becomes:

$$C(t) = 0.6552 - 0.001382\mathrm{E}(t), \tag{3}$$

and equation (2) becomes:

$$\log C(t) = 4.353 - 0.002866\mathrm{K}(t) \tag{4}$$

from which,

$$N(O) = \frac{4.353}{0.002866} = 1{,}519.$$

In order to determine the size of the stock on hand at any time from equation (3) values may be substituted in the following equation:

$$N(t) = 1{,}420e^{-0.003183(t)} \tag{5}$$

In case of equation (4) the stock at any given time may be obtained

TABLE 4.—*Number of boat-days and the number of rainbow trout 2 years old and older caught at Paul Lake, British Columbia in 1932 arranged by weeks*

[The catch per unit of effort *(C)*, the accumulated catch *(K)*, the logarithm of 10 *C*, and the accumulated effort *(E)* are given]

Week No.	Number of boat-days	Number of fish	$C(t)$	$K(t)$	Log 10 $C(t)$	$E(t)$
1	15	49	3.27	49	1.515	15
2	11	53	4.82	102	1.683	26
3	27	104	3.85	206	1.585	53
4	35	144	4.11	350	1.614	88
5	21	48	2.29	398	1.360	109
6	33	85	2.58	483	1.412	142
7	30	51	1.70	534	1.230	172
8	27	69	2.56	603	1.408	199
9	16	40	2.50	643	1.398	215
10	16	58	3.63	701	1.560	231
11	16	46	2.88	747	1.459	247
12	37	112	3.03	859	1.481	284
13	22	49	2.23	908	1.348	306
14	16	41	2.56	949	1.408	322
15	21	27	1.29	976	1.111	343
16	23	19	0.83	995	0.919	366
17	13	17	1.31	1,012	1.117	379
18	14	23	1.64	1,035	1.215	393
19	12	17	1.42	1,052	1.152	405
20	14	14	1.00	1,066	1.000	419
21	15	13	0.87	1,079	0.940	434
22	14	11	0.79	1,090	0.898	448
23	7	5	0.71	1,095	0.851	455
24	8	11	1.38	1,106	1.140	463
25	7	7	1.00	1,113	1.000	470
26	11	9	0.82	1,122	0.914	481

by substracting the accumulated catch to that date from 1,519. Equation (4) is much easier to use than is equation (5).

A rough estimate of the size of the population may be obtained by plotting the value of $C(t)$ against $K(t)$ and fairing a line through the points as suggested by DeLury (1947). Extrapolating beyond the data to the point where the faired line cuts the $K(t)$ axis yields the required estimate of $N(O)$. It tells what the size of the total catch would be if the catch per unit of effort were reduced to zero. Rough methods such as this may be sufficiently accurate for fishery-management purposes.

Both equations place the estimate of the number of fish available to the livery boats at about 1,500. This figure checks fairly well with information derived in other ways, such as the method illustrated in Table 3.

The data of Table 5 were obtained by applying the method of equation (2) to the records for the succeeding years, 1933, 1934 and 1935. The

TABLE 5.—*The population estimate of the stock of 2-year and older fish available to the Paul Lake boat-livery fishery and the recorded catch arranged by years*

Year	Population estimate	Catch
1932	1,500	1,100
1933	4,200	3,100
1934	4,500	3,700
1935	9,000	8,000

recorded catch of 2-year and older fish is also given. Note that the estimate of 4,200 fish available to the boat-livery fishermen in 1933 is in fair agreement with the estimate of the total population as derived in Table 3. The increase in the population shown in Table 5 is the result of a change in the stocking policy which was initiated in 1931. The effect of this change first became evident in the summer and fall of 1932 when the yearlings entered the fishery. The increasing stock on hand and the increased catches which resulted from the new stocking policy are evident from the data in the table.

The methods of estimating the size of fish stocks described above appear to have great promise as an aid to fishery management. Some preliminary work has indicated that they would be equally useful for estimating the size of populations of other animals that are subject to harvesting.

There are certain assumptions underlying the methods which should be pointed out. The most important of these are that:

a the population is closed, *i.e.*, that there is no immigration, emigration or recruitment;

b the catchability as represented by k does not change; the relation between $C(t)$ and $K(t)$ is linear, and there is no competition between units of gear;

c the individuals in the catch are selected in a representative manner.

The validity of these assumptions can usually be judged if the investigator has a thorough knowledge of the biology of the population under study, the methods of fishing, and the factors that affect it.

Before discussing the items that should be included in a creel census that is designed to provide an estimate of the size of a fish population, attention should be drawn to two statistical problems.

First, no attempt has been made to provide estimates of error for $N(O)$. This question has been explored by DeLury.

Second, in experimenting with the data from a physical model and with data from a few actual situations it has become evident that the relation between catch and catch per unit of effort is not necessarily a linear one. It also seems evident that the relation between catch and catch per unit of effort may be different in different situations. One case indicated that when the fishing was good, or when weather conditions were favorable, a greater number of fishermen turned out. This situation led to a curvilinear relationship between catch and effort of the form $Y=X^2$. Prof. R. A. Fisher suggested that this difficulty might be partly overcome by dividing the effort into equal blocks, instead of using equal intervals of time. For example, the unit of effort might be taken as 20 boat-days. The catch per 20 boat-days would then be plotted against the accumulated catch.

In other cases, particularly in the stream fisheries of the heavily populated areas of the East, there is a great turn-out of fishermen at the beginning of the season when the stocks in the streams are high. At this time the proportion of unskilled anglers is great and competition for favorable locations is intense. This type of situation produces an entirely different relation between catch and effort which may be quite difficult to formulate mathematically. It is evident that some attention must be directed toward the fundamental relation between catch and effort before $C(t)$ can be used satisfactorily. The methods suggested here, however, should be most useful for estimating the size of game-fish populations in lakes and ponds.

In considering the application of these methods to creel-census work two types of operation should be kept in mind. In the first, the total effort and total catch are obtained; in the second sampling is used.

In the case of total coverage the census-taker must obtain records of the number of fish caught and the effort expended by each fisherman throughout the season. In addition, he must be able to cope with the requirements of the three assumptions listed above. Emigration and immigration usually can be controlled by weirs. The question of recruitment can be settled by obtaining data on the relative proportions of the different age groups in the population. In addition, the value of the data may be greatly increased ,if observations on conditions that affect the yield per unit of effort are also made.

The value of the data for estimation may be improved greatly if they can be adjusted or stratified according to weather conditions, season, the method of fishing, and the skill of the fisherman. The unit of effort should also be standardized. It could be merely the catch per trip, or it might be defined more exactly as the number of hours actually spent in fishing. The latter measure is undoubtedly superior, if such data can be obtained. However, the creel census must be planned carefully in advance to obtain the necessary data.

In sampling, the same factors as those for total coverage must be considered, but the problem of obtaining *representative* data is very important. An investigation has shown that restricted, stratified random sampling should be used if the criteria of representativeness, adequacy, and cost are to be met efficiently. The essential point is to be able to reason from the sample selected to the total population with a determinable degree of accuracy.

An Example

The following example is offered to illustrate the practical use of the new method. Again referring to the 1932 data from Paul Lake (Table 4) it is assumed that the following facts have been ascertained:

1. From May 1 to June 30 all of the fish in the catch were 2 years old or older. Hence there was no recruitment during this period.
2. By May 15, those fish that were mature had migrated out of the lake into the tributary stream where they were counted through a fish trap. About the middle of June they began to move down to the fish trap to return to the lake. Thus by May 15, about 200 fish had been caught by anglers and 500 had migrated out of the lake

and were not available to the sport fishery. The next problem was to ascertain how many were at large in the lake.

3. In the period from the middle of May to the middle of June, there was a steady drain on the lake population by fly-fishermen and trollers. The fish remained near the surface which behavior provided a fairly constant catchability.

4. An investigation of the type of the fishery revealed that more anglers turned out on favorable days, thus providing a relation between catch (Y) and effort (X) of the form:

$$Y = X^2 \tag{6}$$

hence

$$C(t) = \frac{\sqrt{Y}}{X} \tag{7}$$

5. Plotting $C(t)$ against $K(t)$ in the manner developed above, equation (2), and fairing a line through the points it was found that the population available to the boat-livery fishery in the lake amounted to about 900 fish on May 15.

6. The total stock of 2-year and older fish on May 1, can therefore be accounted for thus:

By direct count:	Catch prior to May 15	200
	Spawning migration	500
By estimation:	At large in the lake on May 15	900
	Total stock on May 1	1600

Thus by the middle of June at the time the spawners were ready to return to the lake, the fishery manager would know how many fish he had on hand. In this case, if the total stock on hand on May 1 was about 1,600 fish, of which 500 had migrated into the spawning stream and 534 had been caught by anglers, then the stock of legal-sized fish left in the lake on June 15 amounted to about 600 fish. Paul Lake was considered to be seriously depleted in 1932 so the fishery manager would attempt to build up the stock and would allow all of the spawners to return to the lake. If, on the other hand, the lake had become overstocked, he might remove all of the older spawners at the counting trap and not allow them to return. He might also encourage the fishermen to catch a greater number of fish to conserve the food supply in the lake.

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AN ANALYSIS OF THE FEEDING HABITS OF RAINBOW TROUT AND LAKE TROUT IN BIRCH LAKE, CASS COUNTY, MICHIGAN[1]

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Abstract

In Birch Lake, an oligotrophic lake in southwestern Michigan, rainbow trout (*Salmo gairdnerii*) and lake trout (*Cristivomer namaycush*) have been stocked at various times in an effort to make the deeper waters of the lake provide more fishing. Over a 6-year period, creel-census clerks collected stomachs of 322 rainbow trout and 25 lake trout taken by anglers. Analysis of the contents of these stomachs revealed that while the two species of trout were competing with each other for food, neither species preyed upon the indigenous cisco population nor competed with it for food. Aquatic insects and fish made up the greater part of the diet of both species of trout. The fish portion of the diet consisted largely of forage species, with yellow perch and centrarchids occurring but seldom in the stomachs. Rainbow trout took very little surface food except during late June, when there was a mass emergence of burrowing mayflies, and in October and early November when many terrestrial insects were consumed.

Introduction

Birch Lake, a popular recreational spot in Cass County, Michigan, has attracted interest in recent years as the site of an experiment designed to provide sport fishing for rainbow trout in a region of the state normally lacking salmonids. So successful have been the initial attempts to establish and exploit a rainbow trout sport fishery that action has been taken by the Michigan Conservation Commission to extend the open season into spring and fall months and to reduce the creel limits as an aid, in line with research findings, to wider utilization of this species by the angling public.

Since 1941, a continuous creel census has been maintained on all fishing in the lake. It has been the practice of the census clerk to collect various data from the rainbow trout checked by him and to take the stomachs of such fish as have not been cleaned by anglers before reporting to him with their catch.

Little has been published heretofore on the feeding habits of rainbow trout occupying a lake of the type more commonly supporting a game-fish population made up of such essentially piscivorous species as mud pickerel, northern pike, yellow perch, largemouth and smallmouth bass and other centrarchids. Biological inventories made by survey parties operated by the Michigan Institute for Fisheries Research during the past decade have shown that Birch Lake supports a rich and varied population of forage animals, both vertebrate and invertebrate, justifying the assumption that an analysis of the game fishes' diet should reveal feeding habits typical of the species and not unduly weighted by availability of only a few restricted forage sources. The present study embraces results of analyses of stomachs collected throughout the greater part of the ice-free season, from rainbow trout 7.5 to 22.5 inches in total length, over a 6-year period. It is felt that the collections cover a sufficiently wide range of season, time, and fish size to establish the standard diet of the species in Birch Lake.

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[1] Contribution from the Institute for Fisheries Research

One of the more specific reasons for an interest in the problem here reported lies in the fact that the cisco (*Leucichthys artedi*) occurs in Birch Lake where it has long provided a gill-net fishery yielding sport and food, for a few days each year, to residents of the vicinity, some of whom feared that rainbow trout might, if introduced into the lake, deplete the cisco population by predation. Another reason was the Institute's desire to link feeding habits with growth-rate studies of rainbows of known age. All rainbow and lake trout in Birch Lake have been stocked from hatchery sources, each fish of known age and marked by fin-clipping to insure subsequent recognition. The growth rate will be treated in a separate report.

DESCRIPTION OF BIRCH LAKE

Birch Lake has a surface area of 308.8 acres and a maximum depth of 95 feet. It is 1.1 miles long by 0.77 mile wide, the long axis lying in a NW-SE direction. The lake is supplied by numerous springs flowing the year around. Through its outlet it is ultimately tributary to the St. Joseph River, which empties into Lake Michigan. The shallow, barren, sandy shoal areas are relatively narrow, and terminate in an abrupt drop-off. The dominant bottom materials of shoals and slope are sand and marl, with some gravel along the shallows of the eastern and western shore. Marl predominates between the 5- and 70-foot contours while pulpy peat forms the bottom at depths greater than 70 feet. The lake is surrounded by wooded, rolling hills.

A survey made on July 8, 1937, revealed the presence of a thermocline between the depths of 15 and 36 feet. On this date dissolved oxygen was present in the amount of 8.3 p.p.m. at the surface, the same at 45 feet, and 4.6 p.p.m. at the bottom (95 feet); pH, as determined with a Hellige disc comparator, was 8.4 at the surface and 7.5 at the bottom; methyl-orange alkalinity was 122 p.p.m. at the surface and 140 p.p.m. at the bottom; free CO_2, absent from the surface to a depth of 27 feet, was present at the rate of 0.3 p.p.m. at 45 feet and of 0.6 p.p.m. at the bottom. A Secchi disc was visible to a depth of 17 feet at 9:00 a.m. on a clear day. With the air temperature standing at 90° F. on July 8, the water temperature ranged from 80° F. at the surface through 75° F. at 12 feet, 50° F. at 39 feet, to 45° F. at 95 feet.

Aquatic vegetation is not abundant, and is largely confined to shoal areas. *Anacharis canadensis* is common to a depth of 18 feet, *Ceratophyllum demersum* and *Myriophyllum spicatum* to the 15-foot contour. *Chara* sp. occurs to a depth of 10 feet. Few other species[2] occur beyond a depth of 6 feet.

TABLE 1.—*Summary, by major categories, of bottom organisms obtained by Ekman dredge from Birch Lake, Michigan, 9:00–11:30 a.m., July 8, 1937*

[Four ¼–square-foot samples taken at each station]

Station number	I	II	III	IV	V
Depth in feet	2	5	29	42	62
Type of bottom	Sand & marl	Sand	Marl	Marl	Marl & pulpy peat
Vegetation	Abundant	Abundant	None	None	None
Volume of organisms per sq. ft. (cubic centimeters)	0.03	1.1	1.3	0.6	0.5
Organisms (numbers)					
Oligochaete worms	..	..	..	45	69
Snails	..	15	..	..	..
Clams	..	6	22	65	1
Scuds	1	14	..	..	..
Crayfish	..	1	..	..	..
Mayfly nymphs	..	3	6	..	1
Dragonfly nymphs	..	4	..	..	..
Midge larvae	4	17	113	92	133
Total organisms per sq. ft.	5	60	141	202	204

Samples of the invertebrate fauna were taken with plankton net and Ekman dredge on July 8. A vertical haul of the net from a depth of 90 feet to the surface yielded plankton organisms at the rate of 2.7 cubic centimeters per cubic meter; a horizontal haul of 100 feet at the surface yielded 2.1 cubic centimeters per cubic meter. Both samples were dominated by Entomostraca. Results of sampling with the Ekman dredge are shown in Table 1. Although many more samples, taken throughout the year, would be required as a basis for an accurate estimate of the total invertebrate fauna production of the lake, the data available indicate a production equal to the average for other oligotrophic lakes in southwestern Michigan that have been surveyed by the Institute (unpublished data).

Species of fish known to occur in Birch Lake are listed in Table 2. It is quite possible that additional species are present as well, especially other cyprinids. All species of trout shown in the table have been introduced at various times from hatchery stocks.

DIET ANALYSES OF RAINBOW TROUT

In all, 322 rainbow trout stomachs were available for examination. Of the total, 165 were from fish between 7⅝ and 12 inches total length

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[2] Other plants known from Birch Lake include *Hydrocotyle umbellata, Najas flexilis, Nymphaea odorata, Nuphar advenum, Potamogeton angustifolius, P. friesii, P. natans, P. pectinatus, P. panormitanus, P. zosteriformis, Ranunculus longirostris,* and *Scirpus acutus.*

TABLE 2.—*Species of fish known to occur in Birch Lake*

[The four species of trout have been introduced]

Northern longnose gar	*Lepisosteus osseus oxyurus*
Cisco	*Leucichthys artedi*
Brown trout	*Salmo trutta fario*
Coast rainbow trout	*Salmo gairdnerii irideus*
Common brook trout	*Salvelinus f. fontinalis*
Common lake trout	*Cristivomer n. namaycush*
Common white sucker	*Catostomus c. commersonnii*
Northern creek chub	*Semotilus a. atromaculatus*
Western golden shiner	*Notemigonus crysoleucas auratus*
Central common shiner	*Notropis cornutus chrysocephalus*
Blackchin shiner	*Notropis heterodon*
Northern mimic shiner	*Notropis v. volucellus*
Northern blacknose shiner	*Notropis h. heterolepis*
Bluntnose minnow	*Hyborhynchus notatus*
Northern brown bullhead	*Ameiurus n. nebulosus*
Tadpole madtom	*Schilbeodes mollis*
Central mudminnow	*Umbra limi*
Mud pickerel	*Esox vermiculatus*
Western banded killifish	*Fundulus diaphanus menona*
Yellow perch	*Perca flavescens*
Logperch	*Percina caprodes*
Iowa darter	*Poecilichthys exilis*
Northern least darter	*Microperca m. microperca*
Northern smallmouth bass	*Micropterus d. dolomieu*
Largemouth bass	*Micropterus salmoides*
Green sunfish	*Lepomis cyanellus*
Pumpkinseed	*Lepomis gibbosus*
Common bluegill	*Lepomis m. macrochirus*
Northern rock bass	*Ambloplites r. rupestris*
Northern brook silverside	*Labidesthes s. sicculus*
Northern muddler	*Cottus b. bairdii*
Ninespine stickleback	*Pungitius pungitius*

and 157 were from specimens between 12⅛ and 22½ inches total length. Practically all of the collections were taken by anglers using a wide variety of baits, including night-crawlers, minnows, cheese, meat, viscera of fish, wet and dry artificial flies, spinners, plugs, and spoons. A very small number was obtained from experimental gill-net catches. Collections were made over the 6-year period from 1941 to 1946, inclusive, and cover a seasonal span from May 23 to December 19, inclusive. A point of interest noted in passing is that with a single exception no fish of the smaller size group was taken after August 31.

On a basis of total volume of stomach contents, the various materials recognizable as bait made up approximately one-fourth (24.8 percent) of the total bulk. In subsequent treatment of the data, known bait materials are excluded from consideration. Only contents of gullet and stomach were studied; intestinal contents were not examined.

Various methods of recording results of stomach analyses have been employed by the many workers in this field. The tabulations to follow have been arranged in a manner which, it is hoped, will provide the reader with a complete picture of the relative dietary importance of the various food organisms, and permit ready comparison with results published elsewhere. Frequency of occurrence of a given food organism in fish stomachs is an important consideration. This information is given

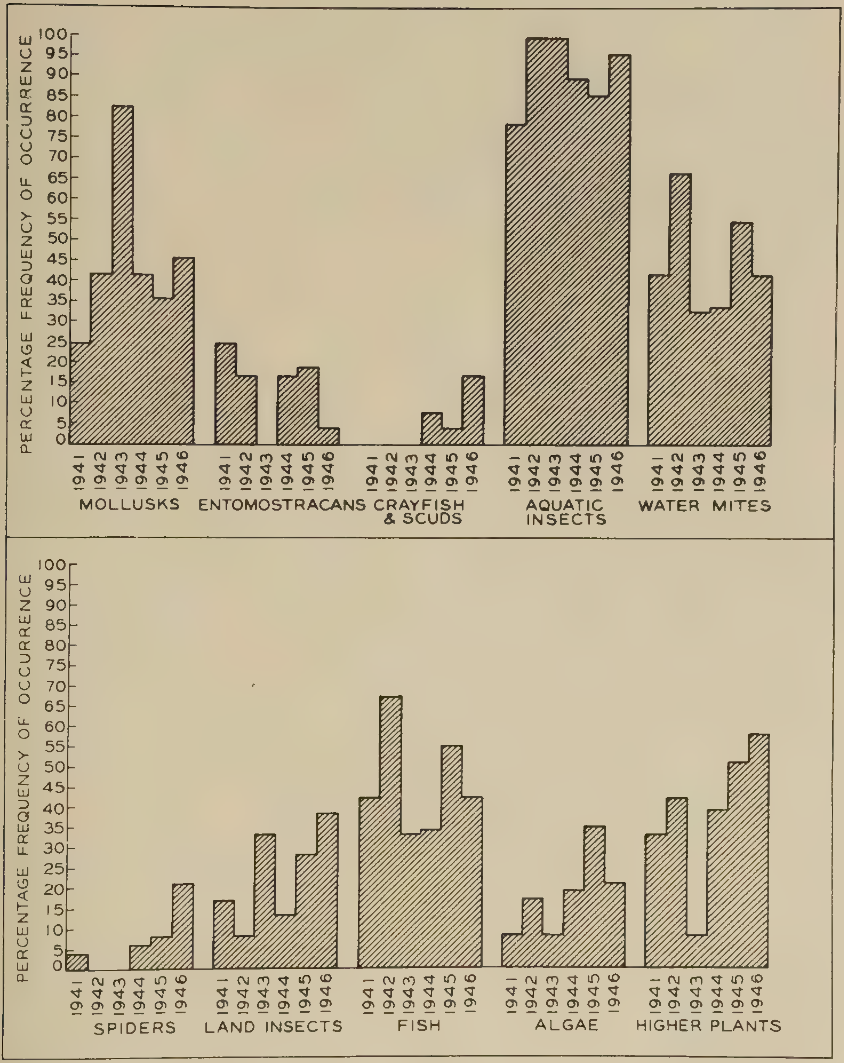

FIGURE 1.—Annual fluctuations in the frequency of occurrence of 11 major categories of food organisms in stomachs of rainbow trout from Birch Lake.

in the tables, together with figures showing the maximum and average numbers of each item in the stomachs containing them. Since many published reports have used volume as the sole criterion for relative importance of food organisms, volumetric figures obtained by fluid displacement are included here. It is the feeling of the writers, however, that volumetric data often may be misleading, especially if unaccompanied by information on numbers and frequency of occurrence of organisms as well, and when based on small series of stomachs. A single bulky specimen, actually of rare occurrence, may assume an unwarranted position of dominance over smaller but commoner food items, whereas digestive action may obscure the real value of rare and common food organisms alike. If stomachs have been collected in large numbers, and over a wide range of time, inequalities due to digestive action will, of course, tend to adjust themselves to the end that certain conclusions may be drawn from volumetric figures.

Figure 1 has been prepared to show the sharp differences which occurred, from year to year, in the frequency of occurrence of the various major food categories in the rainbow trout stomachs. The disparity among years was not great for aquatic insects, but was considerable for other groups. Crayfish and scuds, for example, which accounted for 3 percent of the total diet (computed on a volumetric basis for the entire 6-year period), were completely absent from stomachs collected from 1941 to 1943, inclusive; fish were found in two-thirds of the stomachs taken in 1942, in only one-third of those taken in 1943; frequency of mollusks varied from 25 percent in 1941 to 88 percent in 1943.

In order to determine the extent of differences in feeding due to size of the predator, the trout were arbitrarily divided into two size groups, one comprising specimens 12 inches or less in total length, the other containing the larger fish, from 12⅛ to 22½ inches. Results appear in Table 3, grouped under major categories of food organisms. The data are broken down further in Table 4 so far as species of fishes consumed are concerned. No further breakdown of other food groups has been made on a predator-size basis, since the same species of invertebrates predominated in the stomachs of both size groups.

Table 3 shows clearly that the two most important groups of food organisms in the diet of the Birch Lake rainbow trout were aquatic insects (with few exceptions in immature growth stages) and fishes, the former occurring in 89 percent of all stomachs and accounting for 23 percent of the total volume, the latter occurring in 41 percent of all stomachs and comprising 43 percent of the total volume. The volumetric values for aquatic insects and fish are approximately reversed in the two size groups of trout since the insects are more important than fish in the smaller trout. It is interesting to note, however, that even the larger rainbow trout did not lose their taste for insects, but fed upon them freely. Nearly half (49 percent) of the larger trout had no fish in their stomachs. The occurrence of algae and higher plant materials shows that utilization of vegetable material by lake-inhabiting rainbow trout increases rather than decreases with the size of the fish. Microcrustaceans, represented by various undetermined species of Cladocera and Copepoda, occurred in about one-fourth of the smaller trout but in only one-tenth of the larger. Since ciscoes are considered to feed largely

TABLE 3.—*Feeding habits of rainbow trout from Birch Lake, Michigan, summarized by major categories of food organisms*

[Bait materials excluded from volumetric calculations]

Food item	Stomachs from 165 trout 7⅝ to 12 inches				
	Number of species	Percentage of stomachs containing organism	Number of organisms in stomachs containing them		Percentage of total volume
			Maximum	Average	
Mollusks	8	38	51	5.7	3
Microcrustaceans	...	24	...	...	5
Crayfish and scuds	2	1	1	1.0	trace
Aquatic insects	36	86	478	24.2	40
Water mites	3	30	38	4.1	trace
Terrestrial insects	34	18	19	2.4	1
Spiders	8	5	1	1.0	trace
Fish	8	32	24	3.9	30
Algae	...	20	...	...	1
Higher plants	...	35	...	...	1
Animal debris	...	40	...	...	12
Mixed debris	...	12	...	...	6
Inorganic debris	...	1	...	...	trace
Combined "traces"	...	...	...	...	1
Totals	99	...	...	...	100

TABLE 3.—*(Continued)*

Food item	Stomachs from 157 trout 12⅛ to 22½ inches				
	Number of species	Percentage of stomachs containing organism	Number of organisms in stomachs containing them		Percentage of total volume
			Maximum	Average	
Mollusks	9	41	142	7.2	3
Microcrustaceans	...	10	...	...	trace
Crayfish and scuds	3	10	8	1.5	3
Aquatic insects	37	91	1042	29.8	18
Water mites	3	19	90	6.5	trace
Terrestrial insects	64	26	302	24.7	3
Spiders	12	10	11	2.5	trace
Fish	14	51	72	5.4	48
Algae	...	31	...	...	3
Higher plants	...	54	...	...	3
Animal debris	...	39	...	...	7
Mixed debris	...	18	...	...	11
Inorganic debris	...	4	...	...	trace
Combined "traces"	...	...	...	...	1
Totals	142	...	...	...	100

(Continued on next page)

TABLE 3.—*(Continued)*

Food item	All stomachs combined				
	Number of species	Percentage of stomachs containing organism	Number of organisms in stomachs containing them		Percentage of total volume
			Maximum	Average	
Mollusks	10	39	142	6.5	3
Microcrustaceans	...	17	...	...	1
Crayfish and scuds	3	5	8	1.4	3
Aquatic insects	49	89	1042	26.9	23
Water mites	3	25	90	5.0	trace
Terrestrial insects	87	22	302	15.3	3
Spiders	18	7	11	2.0	trace
Fish	16	41	72	4.8	43
Algae	...	26	...	...	3
Higher plants	...	44	...	...	3
Animal debris	...	39	...	...	8
Mixed debris	...	15	...	...	9
Inorganic debris	...	3	...	...	trace
Combined "traces"	...	...	...	...	1
Totals	186	...	...	...	100

on plankton, it is apparent that the rainbows offer them but little food competition. Decapod crustaceans, which were taken very infrequently, composed 3 percent of the diet, volumetrically, almost solely because of 11 large crayfish (*Cambarus* sp.) taken by trout of the larger size group. Only 10 specimens of *Hyalella knickerbockeri* and 2 of *Gammarus fasciatus* appeared in the 322 stomachs. Mollusks, which also made up 3 percent of the diet volumetrically, occurred in over one-third of the stomachs of rainbow trout of both size groups, and were represented by species of 10 different genera,[3] 9 of them gastropods, the other a "fingernail" clam.

A comparison of Table 4 with Table 2 reveals that of the 31 species of fishes known to occur in the lake, 17, including the unidentified salmonid, were found in the stomachs. Scales of four others, the cisco, white sucker, mudminnow, and Iowa darter, appeared in one stomach each but have been omitted from the tabulation in the belief that they were probably accidentally ingested with bottom material and did not represent fish eaten. Every species of cyprinid known to inhabit the lake was represented in the diet. The mimic shiner, *Notropis v. volucellus*, led all species of fish in frequency of occurrence and number per individual stomach, but was surpassed volumetrically by the less frequent yellow perch. It is noteworthy that rainbow trout of the smaller size group fed scarcely at all on game or pan fishes.

One important question answered by Table 4 is that concerning the

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[3] *Lymnaea, Helisoma, Planorbis, Physa, Valvata, Bythinia, Amnicola, Pyrgulopsis, Paludestrina,* and *Pisidium*

TABLE 4.—*List of fishes found in stomachs of rainbow trout from Birch Lake, Michigan, showing frequency of occurrence, maximum and average numbers per stomach, and percentage of total volume of fish eaten*

[See Table 2 for complete scientific names of fish. "Trace" denotes values less than one-half of one percent]

Food item	165 stomachs from trout 7⅝ to 12 inches				157 stomachs from trout 12⅛ to 22½ inches				All stomachs combined			
	Percentage of stomachs containing organism	Number of organisms in stomachs containing them		Percentage of total volume	Percentage of stomachs containing organism	Number of organisms in stomachs containing them		Percentage of total volume	Percentage of stomachs containing organism	Number of organisms in stomachs containing them		Percentage of total volume
		Maximum	Average			Maximum	Average			Maximum	Average	
Lepisosteus osseus					1	1	1.0	3	trace[1]	1	1.0	2
Salmonidae	...	...	...	...	1	1	1.0	...[1]	trace	1	1.0	...[1]
Cyprinidae	17	7	1.9	19	17	22	3.5	7	17	22	2.7	9
Semotilus atromaculatus	trace	1	1.0	2	1	1	1.0	1	1	1	1.0	1
Notropis volucellus	1	2	1.5	4	1	1	1.0	1	1	2	1.3	2
Notropis sp.	3	9	4.4	5	7	31	5.6	4	5	3.1	5.3	4
Notropis cornutus	...	...	...	...	1	4	2.5	5	1	4	2.5	4
Notropis heterodon	...	...	...	...	1	1	1.0	trace	trace	1	1.0	trace
Notropis volucellus	5	20	4.0	19	10	47	7.8	14	8	47	6.4	15
Notropis heterolepis	1	2	1.5	3	2	2	1.3	...[1]	2	2	1.4	1
Hyborhynchus notatus	2	2	1.3	11	3	2	1.5	3	2	2	1.4	4
Fundulus diaphanus	...	...	...	...	1	1	1.0	trace	trace	1	1.0	trace
Perca flavescens	...	...	...	...	7	2	1.2	24	3	2	1.2	20
Centrarchidae	trace	1	1.0	trace	4	1	1.0	2	2	1	1.0	1
Micropterus salmoides	...	...	...	...	3	1	1.0	8	1	1	1.0	7
Lepomis sp.[2]	3	13	3.8	2	4	3	1.7	1	3	13	2.6	1
Lepomis gibbosus	...	...	...	...	1	1	1.0	...[1]	trace	1	1.0	...[1]
Lepomis macrochirus	...	...	...	...	3	2	1.5	6	1	2	1.5	5
Cottus sp.	...	...	...	...	1	1	1.0	1	trace	1	1.0	1
Cottus bairdii	...	...	...	...	1	1	1.0	trace	trace	1	1.0	trace
Pungitius pungitius	3	4	1.8	2	10	4	1.4	2	6	4	1.5	2
Fish remains	15	...	...	32	25	...	...	17	20	...	...	20
Combined "traces"	...	...	...	1	...	...	...	1	...	...	...	1
Total	...	...	...	100	...	...	...	100	...	...	...	100

[1] Volume included with fish remains

[2] Includes one *Lepomis cyanellus*

TABLE 5.—*Fluctuations in annual occurrence of species of aquatic insects in rainbow trout stomachs from Birch Lake, Michigan*

[The years 1941–1946 are represented by the numbers 1 – 6]

Species[1] and years of occurrence	
Ephemeroptera (mayflies)	1 through 6
Ephemera simulans	4, 6
Hexagenia limbata occulta	1–6
Baetinae	4, 5
Callibaetis sp.	6
Ephemerella temporalis	6
Odonata (dragonflies and damselflies)	1–2, 4–6
Coenagrioninae	2, 4, 5
Enallagma spp.	1, 4–6
Amphiagrion saucium	4
Neogomphoides obscura	5
Stylurus sp.	5
Epicordulia princeps	5
Tetragoneuria simulans	4, 5
Libellula spp.	1, 4, 5
Plathemis lydia	5
Neuroptera (alder flies)	1, 3–6
Sialis infumata	1, 3–6
Plecoptera (stoneflies)	1
Isoperla sp.	1
Hemiptera (water bugs)	3–6
Arctocorisa sp.	3–6
Notonecta undulata	5, 6
Belostoma flumineum	6
Coleoptera (water beetles)	5
Haliplus sp.	5
Coleoptera (cont.)	
Dytiscidae	5
Hydrophilidae	5
Gyrinidae	5
Dryopidae	5
Donacia sp.	5
Trichoptera (caddisflies)	1 through 6
Hydroptilidae	1–6
Oxyethira sp.	4, 5
Banksiola selina	5, 6
Phryganea sp.	1, 2, 4–6
Limnephilidae	6
Leptocella exquisita	1, 2, 4
Leptocella albida	4–6
Oecetis sp.	4
Oecetis eddlestoni	2
Triaenodes tarda	2
Triaenodes injusta	4
Mystacides sepulchralis	1,4,5,6
Brachycentrus sp.	4, 5
Diptera (true flies)	1 through 6
Tipula abdominalis	4, 5
Chironomidae	1–6
Ceratopogonidae	1, 4–6
Culex sp.	1, 5
Chaoborus punctipennis	5
Simulium venustum	3

[1] All forms listed were taken in immature stages except the following: *Ephemera simulans,* both nymphs and subimagoes; *Haliplus* sp. and *Donacia* sp., pupae and adults; Hydroptilidae, larvae, pupae and adults; *Tipula abdominalis* and *Culex* sp., both larvae and adults.

possible influence of the rainbow trout in reducing the cisco population of Birch Lake. It is obvious that there are no grounds for apprehension on this score. The rainbows were not predatory on the cisco in the months stomachs were collected; and since it has been shown in Table 3 that they are not heavy plankton feeders, it seems unlikely that the two species are in competition. So far as feeding habits are concerned, the two species should be able to thrive and each provide a satisfactory fishery.

A wide variety of aquatic insects appeared in the stomachs of trout of both size classes, as is shown by Table 5. Three orders, Ephemeroptera, Trichoptera and Diptera, far outweighed all others in frequency of occurrence, number of individuals eaten, and percentage of total volume (Fig. 2). Chironomid midge larvae and pupae, the most frequently occurring single insect group, included *Polypedilum nubeculosum, Tanypus stellatus, Tanytarsus jucundus dimorphus, Chironomus plumosus, lobiferus,* and *modestus.* Many species of caddis larvae and pupae were eaten. A species of *Phryganea* near *cinerea* dominated, followed by two species of *Leptocella* and an undetermined hydroptilid. Two burrowing mayflies,

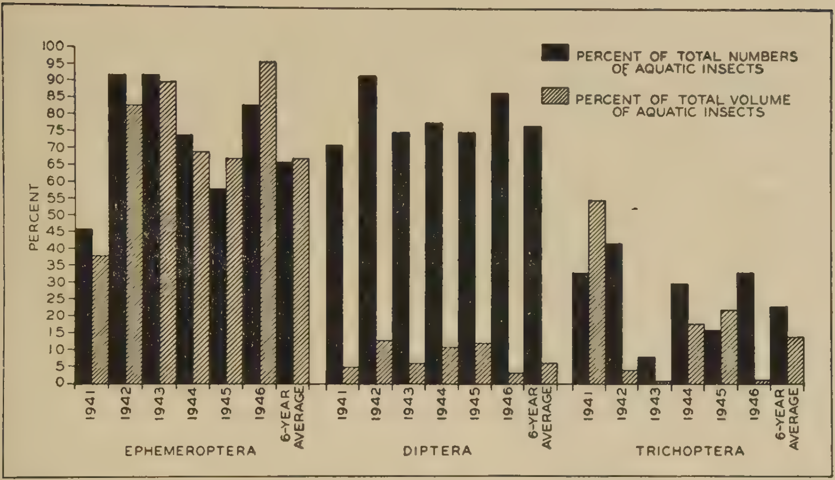

FIGURE 2.—Comparisons of numerical and volumetric occurrence of three orders of insects in stomachs of rainbow trout from Birch Lake.

Hexagenia limbata occulta and *Ephemera simulans,* were the most important element of the ephemeropteran portion of the diet, which accounted for over three-quarters of the total volume of aquatic insects. Of particular interest was the fact that *Hexagenia,* represented only by nymphs, occurred in stomachs throughout the entire seasonal span covered by the collections, whereas the *Ephemera* was represented by nymphs and subimagoes occurring together in stomachs over a very short period of time in late May and was obviously utilized by the rainbows only during its emergence period. The surprising fact that two species whose nymphs presumably possess very similar habits may appear in wide disparity in the trout diet has been discussed elsewhere by one of the authors (Leonard, 1947).

Other peculiarities in occurrence of aquatic insects are displayed by the aquatic Coleoptera, represented by six families but found in stomachs collected in 1945 only; by blackfly (*Simulium*) larvae, and a stonefly, *Isoperla* sp. The last-named forms, represented by only a few individuals, would not be expected in typical lake environments, and may represent a foray into the region adjacent to the outlet stream (which was screened to prevent escape of fish from the lake) by the rainbow trout eating them. Although aquatic Hemiptera have often been considered unpalatable to fish owing to their noticeable odor and the stinging potentialities of certain families, notably the notonectids, representatives of this order were of steady though not abundant occurrence in the stomachs.

It has not been considered profitable to tabulate the terrestrial insect portion of the diet by taxonomic categories. However, it should be noted

TABLE 6.—*Contents of 25 stomachs of lake trout taken from Birch Lake, Michigan, 1941–1946*
[L=larva, P=pupa, N=nymph, A=adult]

Food items	Number of species	Percentage of stomachs containing organisms	Number of organisms in stomachs containing them		Percentage of total volume
			Maximum	Average	
Annelida	1	4	1	1.0	trace
Hirudinea (leeches)	1	4	1	1.0	trace
Aquatic insects	8	80	19	6.5	11
Ephemeroptera (*Hexagenia limbata occulta, N*)	1	76	11	3.7	9
Odonata (*Enallagma* sp. *N*)	1	4	1	1.0	trace
Neuroptera (*Sialis infumata, L*)	1	20	2	1.2	trace
Hemiptera (*Arctocorisa* sp., *A*)	1	4	1	1.0	trace
Trichoptera (*Phryganea* sp., *L*)	1	8	1	1.0	1
Diptera (Chironomidae, *L* and *P*)	3	48	8	3.7	1
Water mites	1	16	9	4.3	trace
Hydracarina	1	16	9	4.3	trace
Terrestrial insects	3	8	2	1.5	2
Coleoptera (*Phyllophaga* spp. *A*)	2	8	1	1.0	1
Lepidoptera (Sphingidae, L)	1	4	1	1.0	1
Fish	16	76	12	2.6	83
Cyprinidae (unidentifiable)	3	16	7	3.0	7
Notemigonus crysoleucas auratus	1	4	1	1.0	3
Notropis spp.	2	8	3	2.5	4
Notropis cornutus chrysocephalus	1	4	1	1.0	1
Notropis heterodon	1	4	1	1.0	2
Notropis v. volucellus	1	8	4	2.5	3
Hyborhynchus notatus	1	4	1	1.0	4
Fundulus diaphanus	1	4	5	1.0	12
Perca flavescens	1	4	1	1.0	17
Centrarchidae	1	4	1	1.0	trace
Lepomis m. macrochirus	1	8	2	2.0	19
Pungitius pungitius	1	20	2	1.4	2
Cottus sp.	1	4	1	1.0	1
Fish remains	...	40	4	1.8	8
Algae	...	4	...	...	trace
Higher plants	...	4	...	...	trace
Animal debris	...	...	...	...	4
Totals	29	...	...	...	100

that land insects appeared very infrequently throughout the summer but were eaten in great quantity during October and early November.

In addition to collecting rainbow trout stomachs, the creel-census clerks covering Birch Lake obtained stomachs from 25 lake trout (*Cristivomer n. namaycush*), the contents of which are analyzed in Table 6. On the basis of this limited series of specimens, it would appear that the lake trout are more strongly piscivorous than the rainbows, but feed upon aquatic insects frequently enough to be rated as direct competitors of the rainbow trout for both insect and fish food organisms. There were no indications that ciscoes, large or small, entered the lake trout's diet. Two lake trout had eaten adult June beetles, and another a large hawk-moth larva, evidence that even these lovers of deep water may now and then take food of terrestrial origin.

The composition of the rainbow trout diet is such as to deserve consideration when management of the Birch Lake fishery is being planned. The suitability of the environment for rainbow trout is apparent from the catholicity of their feeding habits. They are able to utilize: inhabitants of the shallow littoral zone, such as a majority of the immature stages of aquatic insects; the bottom fauna of the deeper zones, as evidenced by nymphs of *Hexagenia* which occur in fair numbers to a depth of 60 feet, and immature chironomids which are abundant even at the lake's greatest depth; and organisms of the open water, such as forage fishes and plankton. Since terrestrial insects and flying stages of aquatic insects were consumed most sparingly except for a few days during the heavy emergence of *Ephemera simulans* in late May and during October when the great bulk of terrestrial insects appeared in the diet, it is obvious that fly fishermen will be able to expect a fair measure of success only when special regulations permit them to fish for rainbow trout during the spring and fall months. High surface-water temperatures which exist during summer seem to discourage rainbows from surface feeding except when their attention is attracted by the mass emergence of *E. simulans* just mentioned, and even this insect was represented in stomachs by many more nymphs than subimagoes, an indication that feeding was heaviest while the nymphs were rising from the bottom to the surface preparatory to transforming. Anglers seeking to take rainbow trout during the summer months must expect to use baits fished at depths where water temperatures have sunk to a point tolerable to the species, generally 15 feet or more below the surface.

Neither the rainbow nor the lake trout appeared to be significantly predatory on the cisco or on any of the game fishes in the lake over the period covered by this study, nor did either seem to be competing with the cisco for food to an important degree. Neither trout species, therefore, is by its presence jeopardizing the cisco population. But the two trouts are themselves competing for the same food organisms, a factor which should be kept in mind when stocking either species. Yellow perch and the various centrarchids played such a small part in the diet of the trouts that it is apparent their populations are not at present being significantly reduced by trout predation. Although yellow perch made up one-fifth of the volume of all fish consumed by the rainbow trout, they appeared in only 3 percent of the stomachs; centrarchids, making up 14 percent of the total volume of fish, were contained in only 7 percent of the stomachs. Numerically, only 90 centrarchids[4] and 11 perch[5] were found in the 322 stomachs. During the warmer months of the year the salmonids and centrarchids probably seldom occupy the same levels of the lake; but if further reductions in the centrarchids and perch populations are desired, an increased trout-stocking program might force the trout to feed more extensively on young bass, bluegills, sunfish and perch during the colder months.

ACKNOWLEDGMENTS

The stomachs upon which this study is based were collected by Rhyner Scholma and C. Troy Yoder of the Institute staff. The limnological data on Birch Lake were obtained by an Institute survey party headed by Dr. David C. Chandler, now of Ohio State University; plants collected by this party were identified by Dr. F. Grassl. We are grateful to Prof. Karl F. Lagler, University of Michigan, for identifying the fishes in all the stomachs reported upon, and to Dr. Henry van der Schalie, University of Michigan, who determined the mollusks. Figures 1 and 2 were drafted by William Cristanelli.

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[4] Centrarchids included 3 largemouth bass, 2–4½ inches long; 6 bluegills, ¾–5 inches long; 1 green sunfish, 4⅞ inches long; and 16 *Lepomis* sp., ½–1 inch in length.

[5] Five of the perch ranged from 3¼–4½ inches in length.

RELATIVE TOXICITY OF SUSPENSION AND OIL FORMULATIONS OF DDT TO NATIVE FISHES IN BACK CREEK, WEST VIRGINIA

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ABSTRACT

On July 23, 1947, a 1-mile section of Back Creek, treated the previous year with a DDT suspension with little damage to fish, was re-treated with an oil spray at the same rate (1 pound per acre). The oil spray killed about six times as many fish as the suspension formula.

Fish began dying within 3 to 4 hours after treatment, whereas several days elapsed before mortality began with the suspension formula in 1946. In addition to larger numbers of the minnow species, some adult game fish were killed. Losses of fish were not as great below the sprayed section as when a suspension formula was used, probably because a good part of the DDT was drifted ashore by breezes or by water currents.

Some species of fish such as bluntnose minnows (*Hyborhynchus notatus*), chub suckers (*Erimyzon oblongus*), and pickerel (*Esox niger*), although numerous, were relatively unaffected. Considerable mortality of largemouth bass (*Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*) occurred in liveboxes placed in the sprayed section, particularly at the lower stations. Largemouth bass nearly 4 inches long survived at a station where 54.0 percent of the 2-inch bass were killed. This fact supplied some positive evidence that fish of larger size are better able to withstand DDT.

INTRODUCTION AND METHODS

On July 24, 1946, a 1-mile section of Back Creek, a warm-water stream near Glengary, West Virginia (Fig. 1), was sprayed with a suspension formula of DDT at the rate of 1 pound per acre (Hoffman and Surber, 1948). This application killed 61 of a large population of the native fishes, composed mostly of smallmouth bass (*Micropterus dolomieu*) and stoneroller suckers (*Hypentelium nigricans*). Wettable DDT powders have been found less toxic to insects than oil sprays by the Bureau of Entomology and Plant Quarantine, Division of Forest Insect Investigations, with whom the writers collaborated in this study. Since it was suspected that oil sprays of DDT likewise might have more effect on fish in streams of forest areas, the present experiment was carried on. The same section of stream treated the year before was used because the fish population, aside from young smallmouth bass and stoneroller suckers, seemed little affected by the previous experiment.

Back Creek is a sluggish stream about 72 feet wide and 20 inches deep. Long pools are separated by short gravel and rubble riffles. The stream gradient is about 0.45 foot per mile, and the rate of flow on July 23, 1947, was estimated to be 40 cubic feet per second.

FIGURE 1.—Back Creek at Station 11.

A pre-treatment inspection of the stream revealed a scarcity of smallmouth bass fingerlings, but adult smallmouth bass were present as during the previous year. Young stonerollers and white suckers (*Catostomus commersonnii*) were not collected in a pre-treatment sample. Whether their absence was caused by unobserved effects of DDT during the preceding season is unknown.

The spawning season of chub suckers (*Erimyzon oblongus*) in the area had been unusually successful, judging from the large number of young scattered through the section. Other species of forage minnows such as bluntnose minnow (*Hyborhynchus notatus*), spotfin shiner (*Notropis spilopterus*), silverling minnow (*Notropis amoenus*) and fallfish (*Leucosomus corporalis*) appeared to be normally abundant. Four- to 5-inch pickerel were common along the stream in the quieter sections where vegetation was present.

The method of evaluating the effect of DDT on fish was identical with the method of the preceding season. A stop seine, 150 feet by 6 feet with ¼-inch meshes was placed across the stream at the lower end of the 1-mile section, and liveboxes were placed above, within, and at Ganotown Ford, 1 mile below the sprayed section. These liveboxes, consisting of wooden frames 26 by 26 by 60 inches covered with wire cloth, were stocked with 50 fingerling largemouth bass (*Miccropterus salmoides*), 50 bluegill sunfish (*Lepomis macrochirus*), and 50 blackhead minnows (*Pimephales promelas*). All fish averaged about 2 inches in length except at Station No. 4 where one livebox was stocked with largemouth bass about 4 inches long. Since depredations by fish-eating birds the preceding season caused large unknown losses, the tops of the liveboxes were covered with wire cloth.

On July 23, 1947, the spraying operation was carried out by personnel of the Bureau of Entomology and Plant Quarantine, Division of Forest Insects, using an N3N biplane equipped with multiple nozzles. The solution employed contained 1 pound of DDT dissolved in 2,846 milliliters of napthenic solution (PD-544-B) and made up to 1 gallon with fuel oil No. 2. The plane was flown about 75 feet above the treetops in applying the spray. Although it was intended to spray a full mile section, the pilot was unable to follow the last 0.2 mile.

The amount of DDT actually reaching the stream was measured with filter papers and glass plates placed at regular intervals across the stream at each 0.1-mile station[1] along the test section. Average deposit of DDT was 0.27 pound per acre (range, 0.0 to 1.86 pounds).

RESULTS OF THE TREATMENT

The spraying was done at 6:15 a.m. on July 23, 1947, and the first affected fish, a silverling minnow, was noticed at 9:30 a.m., 0.8 mile below Glengary Bridge. By 12:45 p.m., large numbers of dying spotfin shiners, silverling minnows, and fallfish could be found along the shore. Many were found several inches above the water level on the shore where they had beached themselves by their nervous darting. Heavy mortality continued throughout the first day and the following day. Some fish were found dead 3 days after spraying, at which time the mortality ceased.

The toxic effect of the oil spray was much more rapid than that of the suspension form used in 1946. The peak of mortality with wettable DDT occurred on the third and fourth days after spraying, whereas the peak of mortality with the oil spray occurred on the day of spraying. Peak of mortality with the oil spray occurred within a matter of hours, as was true in the operation on the Patuxent River (Surber, 1946) where 69.0 percent of all fish found dead were picked up within 9.5 hours after the spraying.

Spotfin shiners and fallfish were much more affected by the oil spray than they were with wettable DDT (Table 1). The fact that bluntnose minnows were not affected by the treatment was of especial interest be-

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[1] Stations were set up at 0.1-mile intervals within the test section; one station was up above the section and one below, as follows:

Station 1, 0.5 mile above Glengary Bridge
Station 2, Glengary Bridge
Station 3, 0.1 mile below Glengary Bridge
Station 4, 0.2 mile do.
Station 5, 0.3 mile do.
Station 6, 0.4 mile do.
Station 7, 0.5 mile do.
Station 8, 0.6 mile do.
Station 9, 0.7 mile do.
Station 10, 0.8 mile do.
Station 11, 0.9 mile do.
Station 12, 1.0 mile do.
Station 13, 2.0 mile do.

TABLE 1.—*Effects of 2 DDT formulations at 1 pound per acre on native fishes in the same section of Back Creek, Glengary, West Virginia, in successive years*

[Total killed by suspension formula in 1946—61; by oil formula in 1947—343]

Days after spraying	Smallmouth bass		Stoneroller sucker		White sucker		Spotfin shiner		Bluntnose minnow		Silverling minnow		Fallfish	
	Suspension	Oil	Suspension	Oil	Suspension	Oil	Suspension	Oil	Suspension	Oil	Suspension	Oil	Suspension	Oil
0	. .	3	. .	. .	. .		. .	104	. .	. .	. .	90	. .	24
1	. .	4	1	1	. .	6	. .	46	. .	. .	. .	10	. .	16
2	. .	. .	. .	1	. .	5	1	4	. .	. .	. .	. .	. .	1
3	11	. .	10	. .	5	. .	. .	. .	1	. .	. .	. .	. .	. .
4	11	. .	4	. .	1	. .	. .	. .	. .	. .	. .	. .	. .	. .
5	5	. .	. .	. .	. .	. .	2	. .	. .	. .	. .	. .	. .	. .
6	1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
7	3	. .	2	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Totals	31	7	17	2	6	11	3	154	1	. .	. .	100	. .	41

Days after spraying	Chub sucker		Yellow-bellied sunfish		Green sunfish		Bluegill sunfish		Brown bullhead		Fantailed darter	
	Suspension	Oil	Suspension	Oil	Suspension	Oil	Suspension	Oil	Suspension	Oil	Suspension	Oil
0	. .	1	. .	. .	. .	. .	. .	. .	. .	4	. .	. .
1	. .	2	1	11	. .	3	. .	2	. .	2	. .	. .
2	. .	1	. .	1	. .	. .	. .	. .	. .	1	. .	. .
3	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	. .	. .
4	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1	. .
Totals	. .	4	1	12	. .	3	. .	2	1	7	1	. .

TABLE 2.—*Sizes of native fishes killed by DDT in 1947 Back Creek spraying operation*

Species	Fork length (inches)								Total
	0.0–0.9	1.0–1.9	2.0–2.9	3.0–3.9	4.0–4.9	5.0–5.9	6.0–6.9	7.0–7.9	
White Sucker......	–	2	8	–	–	–	1	–	11
Stoneroller sucker..	–	–	–	–	2	–	–	–	2
Chub sucker.......	2	2	–	–	–	–	–	–	4
Spotfin shiner.....	–	93	47	14	–	–	–	–	154
Silverling minnow.	1	43	56	–	–	–	–	–	100
Fallfish	–	39	–	2	–	–	–	–	41
Yellow-bellied sunfish	1	–	1	–	–	2	5	3	12
Bluegill sunfish....	–	–	–	–	1	1	–	–	2
Green sunfish.....	–	–	–	–	1	1	–	–	2
Smallmouth bass..	–	3	4	–	–	–	–	–	7
Brown bullhead...	–	7	–	–	–	–	–	–	7
Totals	4	189	116	16	3	6	6	3	343

cause they are a common species in this stream. Two schools of this species each containing several thousand adult specimens were found at Stations No. 6 and No. 11. They were unaffected several days after treatment in both 1946 and 1947. The oil spray affected larger fish more than the suspension used at the same rate the preceding year (Table 2). Fifteen fish exceeding 5 inches in length were killed, whereas in 1946 no fish of comparable size were destroyed. Most of the larger fishes affected were sunfish. No adult smallmouth bass or pickerel (*Esox niger*) were found dead, although the latter were common in this section. Few dead fingerling smallmouth bass, stoneroller suckers, and common suckers were found during the 1947 operation probably because few were present in the stream.

Altogether, 343 fish were killed in this experiment, or about six times as many as in 1946. The aquatic insects were more severely affected also, according to Hoffman and Merkel (1948).

Positive evidence that larger fish are less affected by DDT than smaller fish was obtained at Station 10 where 2-inch largemouth bass were held in a livebox close to another livebox containing bass almost twice as large (3.7 inches). In the livebox containing the smaller largemouth bass, 54.0 percent died compared with none in the livebox containing larger fish.

TABLE 3.—*Effects of DDT in an oil spray on fishes held in liveboxes in Back Creek*

Kind of fish and station	Average length (inches)	Initial number	Losses from DDT	Other losses	Percentage of survival
Station No. 1					
Largemouth bass	2.1	50	0	[1]15	70.0
Bluegill sunfish	2.2	50	0	4	92.0
Blackhead minnows	2.1	50	0	13	74.0
Station No. 3					
Largemouth bass	2.1	50	0	0	100.0
Bluegill sunfish	2.2	50	0	4	92.0
Blackhead minnows	2.1	50	0	0	100.0
Station No. 7					
Largemouth bass	2.1	50	3	0	94.0
Bluegill sunfish	2.2	50	3	1	92.0
Blackhead minnows	2.1	50	16	0	68.0
Station No. 10					
Box 1. (West bank)					
Largemouth bass	2.1	50	27	0	46.0
Bluegill sunfish	2.2	50	12	1	74.0
Blackhead minnows	2.1	49	9	0	82.0
Box 2. (East bank)					
Largemouth bass	3.7	20	0	0	100.0
Station No. 13					
Largemouth bass	2.1	50	0	0	100.0
Bluegill sunfish	2.2	50	0	0	100.0
Blackhead minnows	2.1	50	0	0	100.0

[1] One oversize (3.1–inch) largemouth bass probably responsible for abnormally low recovery of bass and blackheads at end of experiment. Only two bass found dead in this box

The downstream effect of the wettable DDT appeared to be greater than that of the oil spray. A search of the stream in 1947 from the lower end of the test section to 1 mile below this point revealed very few dead fish compared with the preceding season, and only two dead fish were found at the Ganotown Ford (Station 13) whereas a considerable number of dead fish were found in that vicinity during the preceding season. The smaller downstream effect on fish with an oil spray is believed to be caused by the fact that the oil film is easily drifted ashore by breezes as well as by the water current in the bends of the stream. Distribution of DDT through the water was probably hampered by the immiscibility of water and oil.

RESULTS OF LIVEBOX EXPERIMENTS

Fifty each of fingerling largemouth bass, bluegill sunfish, and blackhead minnows were stocked in liveboxes placed at five stations as listed in Table 3. Heaviest losses occurred at Station 10, 0.8 mile below the Glengary bridge, the starting point of the spray run. At this station, only 46.0 percent of the 2-inch largemouth bass survived. Bluegill sunfish and blackhead minnows were affected but not severely. The latter species was more affected at Station 7 where there was a survival of only 68.0 percent. No mortality occurred at Station 13, 2 miles below the beginning of the spray run. Losses in the control livebox, ½ mile above the Glengary bridge were quite large, but a part of the losses were no doubt from cannibalism. Some losses may have been caused by disturbance of the livebox by curious persons frequenting a bathing beach nearby. High survival was characteristic of Station 3 and Station 13.

ACKNOWLEDGMENTS

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SOME INDICES OF LAKE PRODUCTIVITY

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Abstract

In an attempt to evaluate lake-survey procedures some of the chemical, physical, and biological measurements that have been considered possible indices of lake productivity have been examined in the light of 11 years of lake surveys and 6 years of pond rearing of yellow pikeperch. In Minnesota waters total alkalinity and total phosphorus appear to be the most valuable indices. Nitrogen is usually present in excess; sulphates are of most value in considering waterfowl areas; and chlorides, pH, and dissolved carbon dioxide are of little value in comparing waters and judging potential productivity. Potassium, manganese, and iron concentrations also are discussed. Quantitative plankton and bottom-fauna samples have been found unsatisfactory as productivity indices for ordinary lake surveys, and the distribution and abundance of larger aquatic plants are of greatest value when related to waterfowl management. In estimating the potential productivity and formulating fish-management plans for lakes the structure of the fish population and the nature of the lake basin should be considered.

Introduction and Methods

The factors which determine or which are indicative of the potential productivity of fresh waters have long interested limnologists and fishery workers. Much of the basic work on the fertility and productivity of waters was carried out by such classical limnologists as Thienemann and Naumann in Europe and Birge and Juday in Wisconsin who usually did not attempt to correlate the information they gathered with practical problems of fish production. These workers did, however, develop certain ideas and techniques that were borrowed by fresh-water fishery investigators and applied more or less by analogy to fishery problems. One application of the early limnological work was the so-called "lake survey" which was an attempt to evaluate the physical, chemical, and biological conditions of a lake with specific reference to fish production and fishery management.

Extensive surveys of Minnesota lakes were started in 1935. Standard procedure included the making of depth-contour maps showing the extent and nature of aquatic vegetation and bottom-soil types, and determinations of water temperatures, dissolved oxygen, pH, total alkalinity, and total dissolved solids. The fish population was sampled by gill nets and seines and information gathered concerning the use of the lake. As the survey progressed, certain useful ideas emerged, such as a classification of Minnesota lakes according to the types of fish for which they were best suited (Eddy, 1938) but, in general, the information gathered proved to be more of qualitative than quantitative nature. Many of the data secured were difficult to interpret because the indices used had never been evaluated in terms of potential fish production. This deficiency led to a re-valuation of lake-survey methods. In 1942 quantitative sampling of plankton and bottom fauna was discontinued because seasonal variations, errors in sampling, and the labor required to collect and examine an adequate series of samples made the value of such work questionable. Since that year greater emphasis has been placed on the chemical quality and basic fertility of waters, on growth rates of fish, and on the structure of fish populations. In addition to routine field analyses for dissolved oxygen and total alkalinity, laboratory analyses have been made for sulphate-ion, chloride-ion, soluble phosphorus, total phosphorus, nitrate-nitrogen, nitrite-nitrogen, and Kjeldahl-nitrogen.

Emphasis has been placed on water chemistry because a wide range of chemical conditions is known to exist in Minnesota waters and because some general relationship between water chemistry and the management of Minnesota lakes for fish had been noted. It was known also that water quality influenced the distribution and growth of aquatic plants (Moyle, 1945). In an attempt to gain more knowledge of the relationship between water quality and fish production, chemical analyses were made on natural ponds used for the rearing of yellow pikeperch (*Stizostedion vitreum vitreum*) fingerlings. The ponds considered in this paper ranged from 1 to 10 acres in area and from 5 to 10 feet in depth and were managed without forage fish and were not fertilized except by the addition of small amounts of barnyard manure in early spring.[1] These ponds were scattered throughout the state and represented nearly the entire chemical range of Minnesota waters (Smith and Moyle, 1945).

Water analyses cited are all from surface samples taken during the summer. Analytical techniques used are those described in Standard Methods of Water Analysis, 8th Edition (American Public Health Association, 1936) except that turbidimetric estimates of low concentrations of sulphates were made and phosphorus was determined by a modification of Taylor's (1937) method. Series of chemical analyses from experimental ponds, as well as previous work by Surber and Olson (1937), show that the chemical quality of the water varies considerably throughout the year but that analyses of unfertilized waters made during the summer are usually comparable.

Emphasis has been placed on the relationship between chemical quality of water and fish production, but other factors such as the composition of the fish population and the form of the lake basin are also important in estimating potential fish production. Thus, although the standing fish crop of the average Minnesota hard-water lake is about 130 pounds per acre in the littoral area, standing crops of 400 to 500 pounds per acre are not uncommon where the population is largely made up of nonpredacious rough fish. Similarly, fish production in some Minnesota lakes appears to be limited by the small percentage of littoral area.

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[1] Usually about 400 pounds per acre.

WATER QUALITY AS A PRODUCTIVITY INDEX

Total alkalinity.—Minnesota lakes and ponds range in total alkalinity from 5.0 to 350.0 p.p.m. In most waters the total alkalinity is largely bicarbonates of calcium and magnesium with calcium the most abundant metallic ion. Total alkalinity of Minnesota waters increases from northeast to southwest and reflects the nature of the underlying glacial soils and rock formations. Often there is considerable local variation in water quality and soft-water lakes may occur in hard-water areas.

Comparison of annual yields from yellow pikeperch ponds with the total alkalinity of their respective waters (Table 1) indicates that ponds with an alkalinity below 40.0 p.p.m. did not yield as well as did those with harder water. Where total alkalinity is above 40.0 p.p.m., there seems to be no relationship between increased carbonate content and yield. Ponds with a total alkalinity below 20.0 p.p.m. had especially low yields and several of this type which were not included in the tabulation failed completely without apparent reason.

TABLE 1.—*Annual yield of yellow pikeperch fingerlings in pounds per acre and total alkalinity of 69 Minnesota rearing ponds*

Number of ponds	Total alkalinity (p.p.m.)	Average yield (pounds per acre)	Maximum yield (pounds per acre)
7	8.0– 20.0	17.1	50.0
7	21.0– 40.0	28.3	83.0
20	41.0– 80.0	63.3	234.0
15	81.0–120.0	62.7	232.0
20	121.0 or more	48.2	194.0

Comparison of test-netting results[2] from Minnesota lakes of different carbonate hardness shows a lower average rate of catch from waters with a total alkalinity below 40.0 p.p.m. than from harder waters. Above a concentration of 40.0 p.p.m. there appears to be little relationship between average rate of catch and carbonate hardness. Forty-two lakes with a total alkalinity below 40.0 p.p.m. had an average gill-net ratio of 10.12; 26 lakes with a total alkalinity between 41.0 and 100.0 had an average gill-net ratio of 18.10; and 14 lakes harder than 151.0 p.p.m. had an average gill-net ratio of 17.60. Similarly, a consideration of seine hauls from the littoral areas of 42 Minnesota hard-water lakes shows no apparent relationship between the size of the standing crop of fish and water hardness.

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[2] Netting results are expressed as gill-net ratios; that is, the number of fish caught in a standard experimental net of fine mesh size, 100 feet long and 5 feet deep, set for 24 hours. Comparison of gill-net ratios is subject to several sources of error. There is considerable variation in the net catches from a single lake and it is known that gill nets fish selectively. Because nets catch centrarchids and rough fish less readily than the more active game fish, it is likely that the difference in ratios between soft– and hard-water lakes reflect an even greater difference in the total fish population.

A total alkalinity of 40.0 p.p.m. seems to be a natural separation point between soft and hard waters. Naumann (1932) considered 44.0 p.p.m. (25 milligrams of CaO per liter) to be the upper limit for Swedish oligotrophic lakes. The best dividing line between soft- and hard-water floras in Minnesota lakes is about 40.0 p.p.m. (Moyle, 1945). Ellis, Westfall, and Ellis (1946) noted that at concentrations between 45.0 and 200.0 p.p.m., carbonates and bicarbonates have little direct effect on fish. Eddy (1938) stated that most Minnesota trout lakes range in carbonates from 10.0 to 50.0 p.p.m. and that lakes containing warm-water fish have a total alkalinity above 40.0 p.p.m. Minnesota waters with a total alkalinity below 40.0 p.p.m. have a plankton characterized by diatoms and desmids, seldom produce a blue-green algal bloom, and usually have a sparse growth of larger aquatic plants. Rosette plants such as *Lobelia Dortmanna* L., *Eriocaulon septangulare* With. and *Isoetes Braunii* Dur. are typical and larger pondweeds are usually poorly represented or lacking. The lower productivity of soft waters may be related to one or more of several factors. Swingle and Smith (1939) demonstrated that low concentrations of calcium carbonate (below 16.0 p.p.m.) restrict the growth of plankton. Although low concentrations of calcium are associated with low concentrations of half-bound carbon dioxide, carbon dioxide seems not to be a factor limiting the productivity of soft waters. Usually, an excess of carbon dioxide is present as carbonic acid. However, the effectiveness of liming ponds may be limited by the amount of carbon dioxide available to put the lime into solution as the bicarbonate. Low phosphorus and nitrogen concentrations often associated with low alkalinity may limit plankton production in soft-water lakes. Some increase of production in such waters can generally be obtained by the addition of fertilizers containing phosphorus and nitrogen.

Hydrogen-ion concentration and free carbon dioxide.—During the summer the hydrogen-ion concentration, expressed as pH, of Minnesota surface waters is generally between 6.4 and 9.0. Usually soft-water lakes have a lower pH than do hard-water lakes but localized and short-time variation is so great that pH is a poor productivity index. It appears, however, that the distribution of at least some of the typical soft-water plants is related to the lower pH of soft waters (Moyle, 1945). Within the range found in Minnesota waters, ionized hydrogen seems to have little direct effect on fish and no fish kills resulting from sudden fluctuations or abnormally high or low concentrations of hydrogen-ions, such as were reported by Ellis, Westfall, and Ellis (1946), have been observed. Determinations of carbon dioxide (titratable acidity) in lake waters are of little value as a comparative index of productivity because such concentrations are readily and rapidly influenced by life processes of plants and animals.

Sulphates.—The usual range of sulphate-ion concentrations found in Minnesota waters is 0.0 to 500.0 p.p.m. Most lakes have concentrations below 10.0 p.p.m. and higher concentrations are largely limited to the Cretaceous rock area of southwestern and western Minnesota. It appears from observations on Minnesota lakes and fish ponds that sulphates in concentrations below 300.0 p.p.m. of the ion have little or no effect on fish. A similar observation was made by Ellis, Westfall, and Ellis (1946). Rawson and Moore (1944) found that in Saskatchewan lakes many typical warm-water fishes tolerate much higher concentrations of sulphates than are found in Minnesota waters. Minnesota lakes with a sulphate-ion concentration between 50.0 and 300.0 p.p.m. are usually shallow and high in phosphorus, nitrogen, and carbonates. They are highly productive of fish but are subject to frequent winter kills.

The principal value of sulphate determinations in lake management lies in the relationship of sulphate salts to the distribution and survival of larger aquatic plants. Some of the better waterfowl food plants of the great plains, such as widgeon grass (*Ruppia occidentalis* S. Wats.) and bayonet grass (*Scirpus paludosus* A. Nels.) are not found in waters with a sulphate-ion concentration below 50.0 p.p.m. and are best developed where sulphate-ion concentrations exceed 125.0 p.p.m. Most typical plants of high-carbonate waters disappear when the concentration of sulphate ion exceeds 300.0 p.p.m. and are replaced by alkali-water plants or such highly tolerant and ubiquitous species as the sago pondweed (*Potamogeton pectinatus* L.).

Chlorides.—Chlorides occur in Minnesota waters in concentrations usually between 0.0 and 10.0 p.p.m. of the ion. Most waters have less than 5.0 p.p.m. and higher concentrations are found mostly in polluted waters or in areas of Cretaceous rock. Within the range found in Minnesota, chlorides have no apparent effect on the production or distribution of aquatic plants, fish, or animals.

Classification of waters on the basis of carbonate and sulphate content.—As has been pointed out, Minnesota waters can be grouped into several general types according to their carbonate and sulphate content. The scheme presented in Table 2 has proven of value for the comparison of Minnesota waters and for the definition of such nebulous terms as *soft, hard,* and *alkali.* Separations used are all natural and are based

TABLE 2.—*Classification of Minnesota waters on the basis of carbonate and sulphate content*

Total alkalinity (p.p.m.)	Sulphate ion (p.p.m.)	Classification	Productivity	
			Fish	Plant
0.0–20.0	0.0– 5.0	Very soft	Low	Low
21.0–40.0	0.0– 10.0	Soft	Low to Medium	Low to Medium
41.0–90.0	0.0– 10.0	Medium hard	Medium to high	Medium to high
91.0 or more	0.0– 50.0	Hard	High	High
100.0 or more	50.0–125.0	Medium alkali	High	High
100.0 or more	126.0–300.0	Alkali	High	High

upon observed relationships between the chemical quality of the water and the distribution and productivity of aquatic animals and plants. Two of the division points, that between very soft and soft waters and that between medium-hard and hard waters, coincide with the classification proposed by Birge and Juday (1911) for the Wisconsin lakes, but the terms "hard" and "soft" are not used in the same sense as they were used by these authors.

Other factors influence productivity and the assumptions in Table 2 are general and descriptive of ordinary conditions associated with such waters in Minnesota.

Total dissolved solids.—During the early years of Minnesota lake surveys the total concentration of dissolved solids was determined for most of the waters investigated. This analysis included the weight of all dissolved salts plus that of any suspended matter. In many waters total dissolved solids are an approximate index of total salt concentration or salinity but because of varying concentrations of suspended matter and the wide carbonate-sulphate ratio of Minnesota waters, this measurement was found to be of little value.

Phosphorus.—Investigations on both fresh and salt water show that phosphorus is sometimes a limiting factor in the productivity (Welch, 1935; Sverdrup, Johnson, and Fleming, 1942). Total phosphorus occurs in surface waters of Minnesota lakes and ponds in summer in concentrations usually between 0.005 and 0.2 p.p.m.[3] Often, soft waters are low in phosphorus and usually the low phosphorus concentrations are associated with low nitrogen concentrations. Shallow lakes and ponds generally have a higher phosphorus content than deep lakes. In the summer of 1946, 45 Minnesota fish lakes had an average total phosphorus concentration of 0.047 p.p.m. In contrast, 41 shallow waterfowl lakes had an average total phosphorus content of 0.14 p.p.m. and 132 yellow pikeperch ponds an average concentration of 0.12 p.p.m.

Hard-water rearing ponds for yellow pikeperch with concentrations of phosphorus below 0.05 p.p.m. had low yields (Table 3). Since these ponds were high in carbonates, and nitrogen usually was present in excess of actual needs, phosphorus was probably a limiting factor in the fish production. Above a total phosphorus concentration of 0.05 p.p.m. there was little difference in either the average or maximum yield for the categories given in Table 3. However, ponds with total phosphorus between 0.11 and 0.2 p.p.m. consistently produced good yields and 58 percent of these ponds yielded more than the average for the entire series. It would appear, therefore, that the optimum concentration of total phosphorus in this series of fish ponds is between 0.1 and 0.2 p.p.m. Similar phosphorus concentrations are usually associated with heavy algal blooms. Sixteen Minnesota lakes on which heavy blooms occurred during the summer of 1946 had phosphorus concentrations between 0.055 and 0.55

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[3] Total phosphorus as here considered is all the phosphorus in the unfiltered sample, including phosphorus in plankton

TABLE 3.—*Annual yield of yellow pikeperch fingerlings in pounds per acre and total phosphorus in Minnesota rearing ponds*

Total phosphorus (p.p.m.)	Average yield (pounds per acre)	Maximum yield pounds per acre	Number of ponds
0.02 –0.05	11.4	43.5	7
0.051–0.10	71.2	234.0	13
0.11 –0.20	65.4	197.0	12
0.21 or more	67.8	213.0	11

p.p.m. with an average of 0.16 p.p.m. Judging from Minnesota yellow pikeperch ponds with ample nitrogen, phosphorus in excess of 0.2 p.p.m. does not increase the yield and above 0.5 p.p.m. there is danger of oxygen depletion.

The ratio of soluble phosphate-phosphorus to total phosphorus varies throughout the year but is usually lowest in mid-summer when all or nearly all the soluble phosphorus may disappear. At this season the total concentration of phosphorus is usually lowest and subject to least variation.

Our present knowledge of phosphorus content and productivity of Minnesota waters suggests that the scheme presented by Yoshimura (1932) for classifying Japanese lakes on the basis of phosphorus is basically sound. A similar classification for Minnesota waters is given in Table 4.

TABLE 4.—*Classification of Minnesota lake and pond waters on the basis of phosphorus content*

Total phosphorus in summer (p.p.m.)	Phosphorus fertility[1]
0.000–0.02	Low
0.021–0.05	Fair
0.051–0.10	Good
0.11 –0.20	Very good
0.21 or more	Excessive

[1] The "phosphorus-fertility" ratings assume an excess of calcium, nitrogen, and other necessary elements

Nitrogen.—Total nitrogen content (nitrate, nitrite, ammonia, and organic nitrogen) of Minnesota surface waters usually ranges between 0.10 and 2.0 p.p.m. during the summer months. The nitrogen content of soft waters is often low, and deep lakes usually have less than do shallow lakes and ponds. Forty-five fish lakes analyzed during the summer of 1946 had an average total nitrogen content of 0.420 p.p.m. and a range from 0.131 to 0.847 p.p.m. Sixty-five fish ponds had an average total nitrogen concentration of 1.002 p.p.m. and a range from 0.261 to 3.820 p.p.m. During the summer most of the nitrogen is normally in organic form although available nitrogen as ammonia and smaller amounts of nitrates and nitrites is nearly always present. In the latter respect Minnesota analyses agree with those of Wiebe (1931) for the Mississippi River.

Calculations from the data of Birge and Juday (1922) indicate that the average phosphorus-nitrogen ratio for lake plankton in Wisconsin is about 1:5.6. Fleming (1940) gave the somewhat higher ratio of 1:7.2, for marine plankton and Swingle and Smith (1939), while expressing some doubt as to the accuracy of their analytical procedures, estimated that phosphorus and nitrogen were being utilized in the plankton growth at ratios from 1:3 to 1:6. Summer phosphorus-nitrogen ratios in 45 Minnesota fish lakes ranged from 1:3.4 to 1:24.8 with an average ratio of 1:11.1. Only 5 lakes in this series had ratios below 1:6. Sixty-five yellow pikeperch ponds had an average phosphorus-nitrogen ration of 1:11.1 and only 7 ponds of the series had ratios of less than 1:6. It should be pointed out that the ratio between these two elements is important only when concentrations of either nitrogen or phosphorus are low enough to limit productivity. For this reason it is necessary to consider the total concentrations of these elements as well as the ratio between them when interpreting water analyses. The excess of nitrogen over phosphorus in most waters probably reflects the augmentation of the normal nitrogen supply by the activities of nitrogen-fixing bacteria and addition of ammonia-nitrogen with rain water (Lyon and Buckman, 1929).

Because a high concentration of nitrogen is usually associated with a high concentration of phosphorus, separate evaluation of the roles of these elements is difficult. Of the hard-water yellow pikeperch ponds with a total phosphorus content above 0.05 p.p.m., those with total nitrogen below 0.5 p.p.m. yielded less than ponds with a higher nitrogen content. The average yield of nine ponds ranging in total nitrogen between 0.3 and 0.5 p.p.m. was 29.6 pounds per acre; that of 16 ponds between 0.51 and 1.0 p.p.m., 77.3 pounds per acre; and that of 17 ponds with higher concentrations of total nitrogen, 68.3 pounds per acre. However, it appears that nitrogen is only occasionally a limiting factor in the productivity of Minnesota waters.

Since nitrogen seems not to be a limiting factor in the productivity of most Minnesota waters, its determination is of value only when considered in relationship to carbonates and phosphorus.

Other chemical elements.—Other chemical elements, especially potassium, iron, and manganese, have been suggested as factors which may limit the productivity of waters. These elements are all necessary for plant growth and may occur in waters in very low concentrations. Potassium contents recorded for six Minnesota hard-water and alkali lakes range from 0.5 to 9.0 p.p.m. and a range of 0.887 to 13.6 p.p.m. is reported from four Minnesota hard-water fish ponds (Surber and Olson, 1937). Lohammar (1935) found a similar range in a large series of Swedish lakes and noted a few waters with potassium concentrations below 0.02 p.p.m. The lower critical limit of potassium for plankton production is not known but Swingle and Smith (1939) found no increase of plankton when this element was present in amounts greater than 2.0 p.p.m.

Iron has been found in most Minnesota waters analyzed for it. Forty-eight analyses of soft and medium-hard stream waters from the North Shore of Lake Superior show a range of 0.00 to 1.25 p.p.m. with an average of 0.20 p.p.m. Similar concentrations were found in 17 soft-water lakes of northeastern Minnesota analyzed by C. Reif and L. L. Smith, Jr. The iron content of these lakes ranged from a trace to 1.50 p.p.m. with an average of 0.21 p.p.m. The iron content of water from four hard-water fish ponds (Surber and Olson, 1937) ranged from 0.05 to 0.70 p.p.m.

Manganese content of the 17 soft-water lakes analyzed by Reif and Smith is reported as 0.00 and the four fish ponds already mentioned ranged from 0.0 to 0.35 p.p.m. Wiebe (1930) reported a range of 0.044 to 0.120 for the manganese content of the Mississippi River. Lohammar, in commenting upon the low manganese and iron concentrations of some of the Swedish lakes, suggested that iron and manganese may be limiting factors in some waters. In Minnesota, present knowledge of these elements is too incomplete to warrant any definite conclusions.

Some Physical and Biological Indices

It has long been recognized that plankton is the basis of much fish food. A direct relationship between plankton production and fish yield in Alabama ponds was reported by Smith and Swingle (1939), and quantitative relationships between plankton production and production at other biological levels in some waters were summarized by Lindeman (1942). However, plankton production varies greatly throughout the season and it is impossible to be certain that the samples gathered in the course of an ordinary lake survey present a fair picture of the general productivity of the water. Bottom-fauna production is also related to fish production and has been widely used as an index of fish-carrying capacity in trout streams. In Minnesota lakes there is a marked difference in the bottom fauna available in soft and hard waters and this difference is probably related to fish production. Eighteen soft-water lakes had an average bottom-fauna crop of 0.23 gram, dry weight, per square foot and 23 hard-water lakes an average of 1.48 grams. For general lake surveys, however, bottom-fauna samples are of limited value as an index of productivity. The bottom-fauna crop fluctuates considerably throughout the season, sampling methods are subject to large error, and the procedure is laborious and expensive. It appears that a better evaluation of a lake can be obtained from water analyses with much less effort.

Larger aquatic plants have been shown to influence the bottom-fauna production in streams (Needham, 1938) and many relationships between aquatic plants and animals have been pointed out in the literature (Wilson, 1939; Hotchkiss, 1941). Roelofs (1944) who studied aquatic soils and aquatic plant production in four Michigan lakes, found that the lakes stood in the same order when considered on the basis of aquatic plant production per unit and on the basis of reported fishing success. He concluded that " . . . with certain exceptions plant abundance and distribution may serve as an index of lake productivity." In Minnesota the less productive soft-water lakes can usually be separated from the more productive hard-water lakes by observing the occurrence of species of aquatic plants (Moyle, 1945). Generally the production of such plants per unit area is greater in hard than in soft waters. However, the "certain exceptions" mentioned by Roelofs are quite numerous and important. Carp lakes, flowages, and fertilized fish ponds often have large fish populations when few weeds are present. It appears that in large lakes of low chemical fertility, weeds may contribute directly to fish production by increasing the living space available to small aquatic animals and by utilizing the nutrient salts of the bottom soil. In small lakes and fish ponds, however, heavy growth of weeds has been considered detrimental to fish production because the weeds promote the survival of too many small fish and use up nutrient substances otherwise available to algae (Bennett, 1943). Although weed growth is an uncertain index of fish productivity, these plants are of great value to waterfowl. Most Minnesota fish lakes are frequented by waterfowl, and for this reason weed beds are mapped and species noted during the course of lake surveys.

Rounsefell (1946), after considering much of the published data on fish populations and yields, concluded that usually fish production has a straight-line logarithmic relationship to the size of the body of water and that the smaller the lake the greater the production of fish per unit area. His explanation of this relationship is that " . . . the yield per acre of lake is probably correlated with the relative area of fertile shallow water, which is generally much less in proportion to the total area in the larger lakes than in smaller ones, as indicated by the difference in the length of shoreline." This assumed relationship between lake size and proportion of shallow water does not apply to many Minnesota morainic lakes. Some of the larger fish lakes are quite shallow and very productive of fish food over most of their area and the deeper lakes are of moderate size. In Minnesota hard-water lakes, the catch rate of gill nets shows no decline as the size of the lake increases (Table 5). Although gill-net ratios are subject to much error, they do show that, on the average, those fish that gill readily are taken as fast in large lakes as they are in small

TABLE 5.—*Relationship between lake size and average gill-net ratios*

Lake size (acres)	Average gill-net ratio	Number of lakes
0–200	14.16	27
201–500	13.62	32
501–1,000	14.28	25
1,001–5,000	17.06	28
5,001–24,000	20.94	16

lakes. According to creel-census data from 106 hard-water lakes for the month of July 1941, best fishing was in lakes ranging in size from 501 to 1,000 acres. Twenty-one such lakes had an average catch rate of 2.53 fish per man-hour. Catch rates were lower in both larger and smaller lakes: 1.69 for 16 lakes from 40 to 200 acres; 1.81 for 26 lakes between 201 and 500 acres; 1.34 for 22 lakes between 1,001 and 5,000 acres; and 1.12 for 13 lakes larger than 5,000 acres. In contrast to these hard-water lakes, with an average catch rate of 1.80 fish per man-hour, 18 soft-water lakes had during this same month 0.47 fish per man-hour with a maximum rate of 0.75. It appears from these considerations that lake size alone is of quite limited significance as an index of productivity; rather, lakes must be evaluated in the light of water quality and form of the lake basin. Length of the growing season and water temperature are also important (Thompson, 1941) where lakes in different latitudes and altitudes are compared.

As Rounsefell points out, most of the published information on fish populations and yields is not accompanied by data from which a comparison of the habitats that produced the fish can be made. Publication of such data is of considerable value to fishery workers and will eventually lead to better understanding of the factors influencing fish production.

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DEVELOPMENT AND STATUS OF POND FERTILIZATION IN CENTRAL EUROPE[1]

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Abstract

A review of recent European literature on pond fertilization is offered as a foundation for certain phases of American pond-cultural technique. The fertilizing substances, lime, potassium, phosphorus, nitrogen, and carbon, are discussed individually in the light of their usefulness in increasing fish yields and with regard to the important mechanisms through which they are able to effect these increases. European techniques in the employment of fertilizer are described where these are different from corresponding American procedures. In addition, an attempt has been made to integrate divergent aspects of the subject through a consideration of certain fundamentals of trophic metabolism in ponds, the function of pond soils as conservators of nutrients, and microbiological processes relating to the theory of fertilization. A synopsis of the history of pond fertilization in central Europe and a general criticism of research methods are included.

Introduction

The application of fertilizers in fish culture is a practice of long standing in many parts of the world. Recent widespread interest in the United States has made it important to review the experience of foreign, particularly European, culturists and researchers. Customarily, in scientific investigations of all kinds, contemporary work is accompanied by a running review of pertinent earlier literature which it further completes and interprets. In pond-cultural research this is true only to a limited extent, since in general, familiarity with the voluminous and useful European literature is lacking, and in this country we show signs of wanting to begin at the very bottom of the subject, at the point where the Europeans began in 1600, and working our way up alone. Inasmuch as research that disregards earlier findings is not very economical of effort, the following review has been written in an attempt to span the gap between American and European pond culture. It is based upon literature printed after 1900, largely in German.

Although only recently seen in the United States, pond culture is actually one of the oldest agricultural practices in use today. Its genesis, as far as can be discovered, is somewhere in the background of a treatise on agriculture containing a volume on the husbandry of fish ponds written by the mandarin Fanli, a minister of the State of Yu (Chehkiang Province) about five centuries before Christ. Since that time pond culture has remained a more or less prominent method of winning food; centralized first in Asia, then in Europe, but not receiving wide attention in the United States until within the last few years, pond culture has gathered around itself a complex and sophisticated methodology.

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HISTORICAL SYNOPSIS OF EUROPEAN POND CULTURE

The fish ponds of central Europe began to appear in the 14th Century. The first carp ponds were established at Wittingau (Czechoslovakia) in 1358, and for more than 400 years this city was the center of development of fish culture in Europe. Very likely, ponds served at first for storage only, and later perhaps as aquatic stockyards for fattening wild fish. Leonhardt (1906) records a ledger entry dated 1399 from the accounts of a German estate which remarked that a certain sum of money was spent for grain "to feed the carp." Less than a century beyond this date the spawning of carp in artificial ponds had been observed and encouraged, and pond culture set on its way. Another milestone of medieval limnology was passed during the same period when an unknown person noted that shaded ponds did not produce as many fish as those standing in full sunlight, and further, that if an entire hatch of carp were allowed to remain in a single pond (area of about 2 hectares), the growth of the young fish was slow as compared to growth under less crowded conditions. This observation, however, is not quite the birth of the principle of limited yield as we know it, but rather resulted in a popular notion that the absolute size of the *pond* had an effect on the fish. It is interesting to observe that the early Chinese were motivated by a similar idea when they constructed their ponds in the form of canals surrounding numerous islands, believing that the farther a fish must swim in its lifetime, the larger it will be at the end (MacGowan, 1885). The islands kept the unfortunate carp swimming in circles instead of straight lines.

Evolution of fish-rearing practice soon diverged, and neither resulting line of investigation was similar to the one in ascendency now, although the problems which were attacked by earlier German culturists were then of utmost importance, and it is only because they are already well worked out from the practical viewpoint that they are presently neglected. As one feature of this divergence, the 15th Century saw schedules for the progressive transfer of growing carp from one pond to another developed by the culturists at Wittingau and elsewhere. There were, for example, ponds set aside specifically for spawning; these were small and filled with juniper branches (Karpfenneste) to receive the eggs. The branches with eggs attached were then transferred to the "Brutteiche" where the fry were allowed to grow undisturbed for the first summer. Later the young were removed and placed in lower concentration into larger ponds for further growth and fattening. Each year the fish were wintered in special deep wintering ponds. These carp could generally be marketed after 4 or 5 years at a weight of about a kilogram. Similar schedules were in use in Germany up to the beginning of the last war; they had been modified only slightly since the earliest days. Wherever poor growth was realized in spite of efforts to avoid crowding the fish (that is, to avoid putting them into ponds which were too small!), the fish themselves were blamed. Artificial selection of farm animals had been practiced and the concept of good and bad strains was familiar, but there was not even rudimentary knowledge of biochemistry, thus the pond soil, which will turn out to be the archvillain of this particular drama, remained an unsuspected factor until after 1900.

In another direction, much effort was expended at this time to select brood stock (originally the "native" carp of the Danube basin) in such a way as to develop fast-growing and attractive fish. This highly productive line of research resulted in the "Spiegelkarpfen" (partially scaleless) and the "Lederkarpfen" (entirely scaleless) as well as in the special local races (Bohemian, Galician . . .). American carp do not represent a heterogeneous race, but originated from specially selected German strains. The history of these involved experiments in carp-breeding is in itself a large and important chapter in the story of European fish culture (see Knauthe, 1901).

As interest in fish culture spread, techniques became refined, although reasons for the refinements were not generally well understood, and much superstition was associated with the whole methodology. As an example of one of the enlightened viewpoints, Leonhardt quoted the following requirements for good fish production in ponds (from J. Colerus', *"Oeconomia Ruralis et Domestica,"* published at Mainz, 1665): " . . . guten Boden, steten, frischen Zufluss (gut, durchgewärmtes Wasser von Gräben und Bächen) und guten Samen." It was customary to feed the fish mixtures of sheep dung and potter's clay (which was probably better fertilizer than food) and to dry-fallow the ponds with vetch, barley or beans planted in the bottom soil. The barley was usually harvested to pay for the loss of a fish crop during the fallow year, but the legumes were plowed into the soil while they were blooming (now known to be the stage at which nitrogen fixation stops). Pike (*Esox*) were occasionally introduced into brood ponds to reduce the number of fry, having been carefully blinded beforehand to prevent them from laying waste the crop too enthusiastically. Somewhat in contrast to the foregoing, culturists also poured mixtures of honey, wine, camphor, and barley gruel into the ponds to stimulate growth, and rubbed the brood fish with salves made of salt, ginger, and pepper to encourage vigorous spawning. As far as is discoverable, the latter measures were considered to be about as powerful as the former. At this time the exact nature of anoxia was not understood, but its effects were well known, and there are available recurrent observations of "fish poisoning" during warm weather in crowded ponds.

Fish-cultural achievements in Germany by about 1700 were therefore technically imperfect, but advancing. At this time they had already resulted in the organization of a form of agriculture which succeeded in producing a not inconsiderable quantity of human food. It is important to realize that more animal protein can be produced on a hectare of land as carp flesh than in any other form. Thus given the universal acceptance of the carp as an article of diet, justifiably the fame of German and Czechoslovakian fish farming methods spread rapidly across most of continental Europe (and even later to the United States where the movement culminated in the introduction of imported brood stock into a large proportion of eastern American waters in the early 1900's). However, it becomes obvious that true realization of the potentialities of fish farming, as of almost any other form of agriculture, had to await discovery of the basic principles of biochemistry, and this discovery was not forthcoming until 1870 when von Liebig published his monumental works on plant nutrition and fertilization. Until that time, further advance in fish-cultural practice was not of a fundamental sort, but consisted chiefly of refinements on techniques introduced long before.

In 1750, J. G. Leopoldt advanced the concept that fish, like other crops, are strictly a product of the land, and so formed the link between the remark of Colerus about pond soil and modern pond culture founded upon Liebig's *"Chemie in Anwendung auf Agrikultur und Physiologie."* He recommended heavy manuring of poor ponds, crop rotation on dry pond bottoms, and generally concluded that the more closely dry-farming principles were applied to pond farming, the more successful the latter would be. Today we in the United States are just approaching this viewpoint. The 50 years' decline in German carp production in the first half of the 19th Century was probably the result, as Leonhardt maintained, partially of exhaustion of pond soils which had slowly been decreasing in fertility through 200 years of use, and could finally be restored only by systematic fertilization. After 1880, with basic principles newly in hand, another period of rapid advance was possible—advance directly pertinent to our own research into problems of lake improvement and farm fish ponds.

A certain homogeneity has been assumed here in the aims of European and American fish culturists; this assumption is only approximately true. For one thing, the fish produced by central European ponds are an important source of food, not only locally, but as an article for export. In America, the situation is different: fish ponds are not yet of first-rank economic significance. Secondly, the carp is of primary importance in Europe and of none in America, where carnivorous species are more frequently reared. However, the increasing use of American ponds for rearing bait fish, which include mostly species similar in their feeding habits and nutrition to the carp, minimizes this divergence to some extent. And finally, there has been a desire on the part of American culturists to utilize natural bodies of water for cultivation, modifying them in such a way as to secure a high rate of production and at the same time retain a more or less "natural" environment. The basic outlook has been different in Europe where ponds are for the most part designed for utility, being readily drainable, free of shore vegetation and without extraneous species.

Historically, then, European pond husbandry may be divided into two phases. A bedfellow of farming, it developed elaborately on the trial-and-error system; as a subject for limnological research, it has received much attention from biologists at universities and research stations. It is not always possible to distinguish between these two lines of development because the conclusions reached in each usually have been remarkably similar. The now acceptable principle that the underlying soil is the true medium of production forms a foundation for the whole subject. One final remark might be made with regard to the growth of pond culture. The extensive and early development which it enjoyed at the hands of agriculturists has tended to give a "practical" slant to modern investigation. The explanation lies in the fact that such agriculturists were too deeply concerned with the material outcome of their "experimental" ventures to permit themselves the luxury of scientific rigor. The desire for immediately applicable results has to a large extent permeated the field both here and abroad and resulted in the rather aimless accumulation of a great mass of provisionally useful data. But the kernal and chaff have all been piled up together, and it is still difficult to find in the large collection of "Lehrbücher" and journal articles much that could contribute to the present somewhat meagre fund of basic concepts. In one sense, this condition could not have been avoided, for here science was literally centuries behind the common man and is only now catching up. However, we should not continue to be satisfied to deal with the subject as superficially as it has been dealt with in the past; the time has come to begin searching for fundamentals (see Langhans, 1922).

BOTTOM SOILS

Emil Walter has reiterated in his numerous writings on pond fertilization that the chemistry of pond water, considered separately, means relatively little to the culturist. Continuing through European literature, one is impressed that all generalizations about fertilizers are made in terms of the bottom soils. Before considering the fertilizing materials themselves, it is therefore important to devote some attention to the ways in which pond soils, in a purely mechanical sense, may influence the economy of fertilization. Here the best approach is a brief listing of the important functions of these soils followed by a consideration in later sections of those functions as they effect specific fertilizers.

The bottom has been divided into two biologically significant regions, an upper, loose, well aerated, and often highly colloidal layer of decomposed organic material, plant debris, . . . (Schlammschicht), and a lower anaerobic zone, differing widely in composition from place to place and often containing a large proportion of mineral matter (Bodenschicht). The ability of these soil layers to direct certain processes in the pond is the result of the special properties listed below.

1. The mineral composition of pond water is to a large extent a reflection of the mineral composition of the soils of the pond bottom and the surrounding basin, *e.g.*, alkaline water results from calcium-rich soil.

2. The often predominant colloid fraction, consisting of humic substances, ferric gels, and clay is a powerful adsorbant of certain soluble nutrient elements and a governor of their distribution among pond organisms. Though the adsorption of ions and the electrokinetic behavior of soil colloids is not yet clearly understood, the gross effects of such processes have been established. The advance of colloid science will be accompanied by elucidation of conclusions which have heretofore been accepted by European culturists in a general sense only.

Base-exchange and adsorption in colloidal soil systems have been discussed in several general works (Baver, 1940; Waksman, 1938; and others). Demonstration of the importance of this behavior in pond culture has come from several sources. Breest (1925) observed that there were, in "resting" ponds, substantial discrepancies in the mineral content of water samples from various depths in the pond, *i.e.* the thin layer of water in contact with the bottom contained less potassium than the water from the soil, but more than water from upper layers. In laboratory experiments he discovered that if soluble potassium salts were added to a soil suspension in water, potassium began to disappear from solution, and that after 2 or 3 weeks had elapsed, an equilibrium was reached in which the water contained only a small fraction of the potassium originally added. As the potassium was removed from the water by agents other than the soil, more was released from the latter, which appeared to be acting as a reservoir. As the results of experiments with a soluble dye (methyl violet) instead of potassium, Lantzsch (1924) concluded that the adsorptive capacity of soils varies approximately with the proportion of colloidal material in them, and also with the proportion of organic matter, which in non-clay soils approximates the colloid content. Demoll (1925) listed PO_4^-, K^+, NH_4^+ as strongly adsorbed, NO_2^- and NO_3^- as only weakly so. Thus, the addition to the *water* of these substances in quantities necessary to produce a certain desired concentration carries no guarantee that its composition will remain fixed for more than a very short time.

Additions of lime to previously unfertilized and very unproductive moor ponds whose bottoms are chiefly colloidal organic muck (Schlamm) often permits immediate and phenomenal increases in yield. Walter (in Demoll, 1925) observed that lime alone raised the carp production of such a pond (Lüneberger Heide) from 80 to 360 kilograms per hectare in a single season. In these ponds, lime flocculates colloidal humus and reduces its adsorptive capacity, and thus releases previously adsorbed nutrients, fertilizing the water (Knauthe, 1901, gave extensive documentation on this point). This often observed phenomenon has resulted in the dictum "Kalk macht reiche Väter und arme Söhne." It is "impoverished sons" because after two or three lime treatments, the nutrient supply of the bottom becomes exhausted, and artificial fertilization must be resorted to in order to maintain high yields. As another indirect demonstration, Walter (1926c) recorded that phosphorus is as effective in ponds with a slow exchange of water as it is in stagnant ones (Wielenbach, near Munich). He explained that most of the phosphorus is adsorbed in the bottom and cannot wash out of the pond.

3. The bottom is also the medium in which live the diverse microorganisms that are responsible for the decomposition of organic debris and for chemical transformations such as conversion of organic phosphorus and nitrogen to soluble compounds, oxidation of ammonia, production of carbon dioxide, and possibly fixation of free nitrogen. These organisms are chiefly bacteria (Waksman, 1941) but some fungi also may be quite important (Baier, 1935; Weston, 1941; Umbright and McCoy, 1941). In general, the rate and nature of decomposition are determined by the availability of oxygen, reaction of the substratum, and the presence of certain essential substances.

Where the bottom is not well aerated, decomposition is slow, and its products are reduced or only partially oxidized compounds (*e.g.* hydrogen sulfide, methane, short-chain fatty acids). These materials are undesirable inasmuch as their accumulation is likely to lend a strongly acid reaction to the soil (if the latter is not naturally buffered) and further decrease bacterial activity, resulting eventually in accumulations of peat and in reduced productivity. Naturally acid soils (natural peat, bog soils, . . .) are similarly subject to low rates of decomposition.

4. Under certain conditions the bottom is a direct source of nutrition for the fish insofar as it may contain an extensive fauna of insect larvae, small molluscs. . . . Carp also eat quantities of pond mud, subsequently extracting food in the form of organic debris. The rooted aquatic plants which the bottom supports are also a source of food in addition to forming, when they die, a carbohydrate substrate for certain useful bacteria. This plant debris is of particular importance in ponds where reliance is placed only on inorganic mineral fertilizers.

Management of the bottom therefore, has several aims. A soil must be built which is neither so adsorptive as to impoverish the water of nutrients nor so inactive as to permit excessive loss of nutrients by seepage and outflow. It must be loose and sufficiently aerated to permit rapid oxidative decay, and with buffering properties strong enough to overcome accumulations of acidic products of decomposition. In addition, the soil should provide a suitable medium for the growth of bottom organisms and soft aquatic plants. These aims are achieved in two general ways: by application of suitable chemicals (lime) and by direct treatment of bottom soils after drainage of the pond. The first is discussed in a later section. The second is described in the following paragraphs.

Periodic dry-fallowing is almost universally a part of European cultural practice. In fact, popular opinion has established that undrainable ponds are so far from controllable as to be practically worthless for rearing fish (see papers even as early as Gasch, 1883. Fallowing appears to hasten the process of decomposition and to accelerate the cycle of internal nutrition. All growing ponds are wintered dry, the fish held in the meantime in special wintering ponds. At regular intervals ponds are dried down for a full calendar year. In older practice, crop plants or legumes were grown on the dry soil; this procedure has recently been discouraged by some researchers (see Demoll, 1925), although the practice has the economic advantage of a yield of barley where there is none of fish. If excessively large crops are expected, a pond may be spoiled by this technique (Knauthe, 1901). Demoll is unenthusiastic about any form of planting, but believes that it might be useful where the soil contains little organic material or is excessively compacted. His opinion extends also to mere mechanical disturbance of the soil surface with a harrow, and he considers that deep plowing is decidedly harmful since it buries the most active layers of soil. Kreuz (1928) dealt extensively with mechanical treatment of dry pond bottoms (Dülmen in Saxony). Plowing has been recommended in this country as a method of controlling emergent vegetation (Wiebe, 1935); the same control is achieved in Europe by cutting the plants (*Typha, Sparganium, Carex*, . . .) below the water surface with special knives.

It is possible that drying down ponds for long periods is harmful to useful benthic organisms, particularly insect larvae (Schiemenz, 1922). Nordqvist (1925) investigated dry pond bottoms with this possibility in mind, and found that *Chironomus* larvae are able to survive wintering in dry ponds provided temperatures are not so severe that the larvae cannot burrow beneath the frozen crust. He mentioned that many larvae were destroyed by birds following drainage. It is unlikely that the quiescent stages of zooplanktonts suffer from winter drying.

Gross correlations indicate that periodic drying alone raises fish production of ponds (Czensny and Wundsch, 1918; Doose, 1926). Closer observations have indicated that the pH of pond soils is raised during periods of fallowing (Wiesner, 1934). Some benefit is claimed from reduction in concentration of parasites. Often the incorporation of organic fertilizers (manure, hay, slaughterhouse wastes, sewage sludge, green manure, etc.) with the dry soil of drained ponds makes it possible to avoid difficulties which would arise from oxygen deficiency if these substances were applied to pond water (Schäperclaus, 1933; Kreuz, 1928; and other manuals).

LIME

Frequently encountered references to the heavy liming of fish ponds in Europe reflect the low calcium content of soils in regions where fish culture is extensively practiced. In the United States, pond culture has not spread sufficiently to occupy large strongly calcium-deficient areas. Consequently the emphasis laid upon lime in German practice may seem somewhat misplaced. Juday *et al.* (1938) used lime in fertilizing a small soft-water seepage lake in northern Wisconsin, and Compton (1943) recommended that it be applied to ponds in small quantities to neutralize acidity resulting from decomposition of ammonium salts used as nitrogen fertilizers.

The importance of lime lies in its ability to change drastically certain properties of bottom soils. These changes and their significance may be summarized in the following way:

1. Lime generates an alkaline reaction and acts as a buffer in the presence of all acids. Categorically it can be said that a weakly alkaline reaction (pH 7 to 8) has been found most productive in fish ponds (Demoll, 1925; Walter, 1926b, 1934; . . .) and that very acid waters are distinctly undesirable. At the Wielenbach ponds, high fish production is maintained even though the water reaches pH 12. At pH 5.5 fish develop hypersensitivity to bacterial parasites, and are not generally able to survive a reaction lower than pH 4.5. Apart from a direct effect on fish, acidity impedes the recirculation of nutrients by reducing the rate of decomposition and inhibiting nitrogen fixation (see below).

2. The calcium in lime will displace certain other fertilizing substances from organic colloidal systems, thus making available greater quantities of such materials as K^+, PO_4^-, . . .) when they are applied during the same season.

3. In the presence of calcium carbonate, colloidal humus gels are flocculated, this increasing the mean particle size of the soil and giving it a loose "crumb" structure (Krümelstruktur) thereby improving permeability and aeration. At the same time, the ability of these colloids to liberate hydrogen by interacting with neutral salts is reduced, resulting in conditions more favorable for rapid bacterial decomposition of organic matter accumulating in the bottom (see Waksman, 1938, p. 326). It has been inferred (Demoll, 1925) that the addition of lime before fertilization with phosphorus will save the latter from precipitation in iron-phosphorus complexes (Ohle, 1937), presumably because the lime itself removes iron from solution in pond water. It is doubtful whether reactions of this kind can be predicted with exactness in view of their complicated nature where carbon dioxide and oxygen concentrations cannot be accounted for accurately. It is more correct to say that the solubilities are determined by interdependent equilibria rather than completed reactions.

4. The carbonate-bicarbonate system is apparently involved in the respiration of plants. The carbon dioxide resulting from a condensation of two molecules of calcium bicarbonate is readily used by algae and higher plants as a carbon source for carbohydrate synthesis (Maucha, 1929; Ruttner, 1926; Shutow, 1926; Gessner, 1932). Thus because of

its acid-buffering capacity, lime increases the ability of water to store carbon dioxide.

5. Under special conditions it may be necessary to provide metabolic calcium for fish. However, Wingfield (1940) was unable to demonstrate a difference in growth of trout reared in waters of different calcium content, or any difference in the calcium content of the bones at the conclusion of the experiment. Though there is undoubtedly a necessary minimum concentration of calcium, it is probably low enough that other causes of poor production would intervene before the fish themselves were affected (see also British *Salmon and Fisheries Report* for 1937. London).

6. The addition of lime as CaO to the dry pond bottom has been suggested as the safest way of eliminating the larval stages of various fish parasites which would be concentrated there after draining (Schäperclaus, 1931; Kreuz, 1928; Knauthe, 1901; and most texts and manuals). This statement can hardly be challenged, although it must be born in mind that unslaked lime is by no means a selective disinfectant and probably will eliminate the entire benthic population when it is applied in doses sufficiently large to do away with parasites.

Lime is usually applied to the pond as solid calcium carbonate. Schäperclaus has published a table (1938) in which proper dose can be read opposite pH value for the pond soil. This simple method would seem to be the best for deciding on an appropriate application. The alkalinity of the water is not always a satisfactory criterion of lime deficiency since it varies within wide limits from day to day and even from hour to hour within a single day. Calcium carbonate precipitated by plants will not be included in determinations of soluble alkalinity. Other than Schäperclaus' table, there is no rule-of-thumb to guide culturists in the use of lime. Perhaps the most definite statement is, "Sauren Böden wird so lange Kalk zugesetzt bis die saure Reaktion in eine alkalische übergeht, und sehr zähem, schwerem Boden wird Kalk biegefügt bis eine feinere Krümelstruktur erreicht wird." (Demoll, 1925, p. 81). The alkaline reaction of certain phosphorus fertilizers (basic slag) should be observed and allowances made when they are used (Demoll, 1925).

POTASSIUM

The small amount of potassium present in many natural pond waters and soils has brought this element under consideration as a fertilizer (Walter, 1926b). Where substantial quantities are present naturally, applications in fertilizers are not always followed by increased yields of fish. Demoll cited Fischer's analysis of the Wielenbach ponds—1.65 to 1.78 percent potassium (as K_2O) in the soil and 1.35 p.p.m. in the water—and observed that in these ponds, potassium fertilization which raised the water content to 11 p.p.m. was without effect on the yield of fish. Optimum concentrations of this element are not known.

Potassium is taken up readily by plant tissues and is particularly effective in stimulating the growth of the soft underwater flora (*Potamogeton, Myriophyllum, Anacharis, Ceratophyllum, . . .*); thus the control of potassium in a pond is associated with the management of aquatic plants. During rapid plant growth potassium from the water and soil is stored in the tissues to be released later when the plants die back and decompose, and then held in the bottom by adsorption or lost in the effluent or through seepage. In any event, most of a pond's potassium is not free in solution and may be overlooked by routine water analysis. As might be expected, ponds with sandy, non-adsorptive soils are usually potassium-poor and respond most markedly to fertilization. Other than very general observations of this kind, however, there is little consistency in the results of most investigators.

Demoll (1925) obtained increased production by using potassium alone and found that it hastened the process of muck formation (Schlammbildung) by stimulating rooted plants. However, most experiments yield rather equivocal results and the generalization most often found is that potassium alone is not a particularly effective fertilizer. In combination with others, particularly phosphorus, it does not yield results which are much clearer. Nolte (1932) obtained a mean difference in yield of 44 kilograms per hectare of carp between ponds fertilized with potassium + phosphorus and phosphorus alone. This experiment was performed in a moor pond where an original potassium deficiency probably existed (Knauthe, 1901). At Wielenbach, on the other hand, where the potassium content of the soil is rather high, Walter (1925, 1926 b, 1926c) could not demonstrate that potassium further increases yields attained from phosphorus. Nolte's findings are substantiated far less often than Walter's. It is not unlikely that phosphorus is much more often naturally deficient than potassium and that increased yields following the addition of potassium + phosphorus are chiefly the result of the phosphorus. In the Sachsenhausen (near Berlin) experiments (Demoll, 1925) the size of yield from applications of potassium + phosphorus in different proportions appeared to vary with the absolute amount of phosphorus in the combination. Experiments of this kind generally do not take into consideration potassium already present in plants and in the soil.

Often the results from potassium appear to be erratic and characterized by peculiarities which are not well understood. Harmful effects, chiefly arising from superabundant growth of algae and rooted plants, have been observed where readily soluble potassium salts (*e.g.* KCl) are applied. At Sachsenhausen, fertilization with phosphorus alone resulted in a seasonal reduction of 50 percent in the total nitrogen of the soil. If potassium is applied with the phosphorus, there is usually an increase over the same period of about 60 percent. These facts suggest that the effect of potassium is partially bacteriological. A greatly increased growth of rooted plants may also be responsible for this accumulated nitrogen. In this regard, Järnefelt (1926) found that the destruction of cellulose in a "gyttja" substratum is inhibited by potassium.

When potassium is able to improve the growth of carp, young fish respond in a much more pronounced fashion than do older ones (Demoll, 1925). The explanation for this difference is not obvious. It may be that potassium selectively stimulates organisms which are most important as food for the small carp, or that the direct physiological involvement of potassium is different in fish of different ages. The effect of acid and alkaline water on the growth of brown trout has been described by Frost (1945), who found that the greater size of trout from alkaline streams can be attributed almost entirely to increased rate of growth during the first year. This may be a parallel situation in which calcium rather than potassium is involved.

Walter suspected that the benefits accruing from fertilization with potassium are indirect, that is, that when potassium displaces hydrogen from soil colloids, dilute acids are formed near the bottom in which phosphorus is more soluble. In this way potassium may increase the effective dose of phosphorus.

Potassium is usually applied in the form of soluble salts, generally the chloride (naturally occurring Kainite, a mixture of KCl, NaCl, and $MgSO_4$ is widely available). Applications are generally made once a year. The excessive chloride added with salts like Kainite is believed to have a deleterious effect on pond soils, producing compaction and "crusting" of the bottom surface. The effect of the excesses of sodium and magnesium is largely unknown. Magnesium does not appear to be useful as a fertilizer (Demoll, 1925).

PHOSPHORUS

Phosphorus is undoubtedly the most important single fertilizer. Never present naturally in very great quantity, it is seemingly easily lost from the trophic cycle of ponds. It has frequently appeared to assume the role of limiting factor, and competition for it has been ascribed a reason for periodicity of plankton blooming (Pearsall, 1932; Harvey, 1939; Wiebe, 1935; . . . See also Hutchinson, 1944). It is at least accurate to say that the use of phosphorus in fish ponds is usually followed by increased yields. According to Demoll (1925), fertilization with phosphorus may be universally recommended even where there is no forehand knowledge of chemical conditions in a pond. So few are at variance with this opinion, that it is unnecessary to pursue the point any further.

As with other fertilizers, we do not know precisely what a deficiency of phosphorus is. A definition can hardly be based on phosphorus content of pond water, which fact is evident from Breest's (1921) description of the distribution of the element in the Wielenbach ponds. Surface water there contains 0.03 milligrams per liter (soluble), but the amount is greatly increased in the layer of water adjacent to the pond soil (0.23). Fischer (1917) found in the same place that water entering the ponds contained only 0.02 to 0.06 milligram per liter. He made the surprising remark at the same time that the pond soil, to a depth of 30 centimeters, contained "several thousand" kilograms per hectare of phosphorus (expressed as the pentoxide). In general, surface-water samples contain amounts in the order of 0.0 to 0.50 milligram per liter (soluble), and the content of pond soils has been little investigated. It is instructive to view phosphorus in the light of what is known of the activity of bottom soils.

Phosphorus added to a pond in soluble compounds may be removed from solution by a number of mechanisms which do not act independently of one another. In alkaline water where there is an excess of calcium, phosphorus may precipitate as tricalcium phosphate ($Ca_3(PO_4)_2$). This salt is converted to the more soluble di- and monocalcium phosphates as the pH of the water is reduced (*e.g.* when carbon dioxide production increases—see Gessner, 1939). In the presence of iron, insoluble ferric phosphate may be formed, or the phosphorus may be combined physically with micells of ferric hydroxide which are present under certain conditions (Mortimer, 1941, 1942; Hutchinson, 1944). In addition, it may be adsorbed directly on organic soil colloids (humus) whose nature is not clearly understood (Ohle, 1937; Waksman, 1938; Berl and Schmitter, 1929; Nemec, 1931; Einsele, 1941). Under these circumstances, phosphorus will tend to accumulate in the bottom in insoluble forms where it is not available to the phytoplankton in general, although some algae may be able to use adsorbed phosphorus more or less directly (Harvey, 1939). The resolution of this phosphorus is the result also of several processes.

Although the greatest accumulation of insoluble phosphorus is at the pond bottom, it appears nevertheless that this is the region of greatest phosphorus solubility. Bacteria can use particulate phosphorus in a microzone surrounding the cell and thus the element may be passed on through food chains involving protozoan or crustacean intermediaries. Increased solubility of strongly basic phosphates may be the result of local acidity from base-exchange, acid products of decomposition, or other special conditions around the roots of aquatic plants. Beneath the surface of the soil where oxidation-reduction potentials are lowered, due chiefly to lack of rapid oxygen renewal in the presence of processes which are using oxygen rapidly (decomposition), colloidal complexes of ferric iron are made soluble by reduction and phosphorus adsorbed on them is released. Since these processes are all restricted to the vicinity of the bottom, only this region contains significant quantities of phosphorus in solution.

The phenomenon of phosphorus retention has been demonstrated in several indirect ways. Walter found that the addition of an entire year's allotment of phosphate in a single dose did not succeed in raising the phosphorus content of the water more than momentarily although effects of the fertilization were apparent in the growth of fish at the end of the season. In fact, it is well known that phosphorus applied one year is still able to elicit a response in years following (Breest, 1921). Because of such controls, Walter did not believe that there was any advantage in small applications of phosphorus spread over the entire growing season, but recommended that the whole dose be applied at once in the spring. Rooted aquatic plants seem often to benefit from fertilization with phosphorus. Since the transpiration stream of plants is upward from the roots, mineral nutrients are probably absorbed from the bottom even though the whole plant is immersed in a dilute nutrient solution (Gessner, 1933). This fact may explain the observation that phosphorus is able to stimulate rooted vegetation without effecting, or even at the expense of, plankton algae (J. C. Neess and A. D. Hasler in a 3-year experiment in minnow culture at Madison, Wisconsin, and in a personal communication from Dr. R. Demoll). The artificial acidification of the bottom by applying salts that yielded strong acids by base-exchange (*e.g.* $CaSO_4$) was attempted by Walter but without improving the yield, thus ostensibly without releasing phosphorus. It is not in general the acidity of the bottom which determines the *availability* of phosphorus, however, but the acidity of the free water; hence such large quantities of these salts would have to be used as to make the environment unsuitable for the growth of fish, even if the hydrogen reserve of the soil were sufficient.

It is interesting that after many years of experimentation, Walter decided that about 17 kilograms per hectare of phosphorus (applied as superphosphate) was an optimum dose. In a variety of ponds he was unable to increase his yields further by application of more, and not able to reach maximum production with less. This figure has been taken from his article and appears in most later manuals on pond fertilization(*e.g.* Schäperclaus, 1933). Why this optimum should prove to be a constant (with some exceptions—see Goepfert, 1931) is difficult to understand. It is, of course, at variance with results obtained independently in this country.

NITROGEN

Nitrogen fertilizers, particularly inorganic nitrogen compounds, are not used as extensively in central Europe as in the United States. In fact, many investigators consider that they may be dispensed with entirely without any effect on the rate of fish production. It is not a question of the importance of nitrogen itself to pond metabolism but one of the ability of ponds to supply their own nitrogen. The prevailing opinion is that a properly managed pond can function independently of an outside source of fixed nitrogen.

In general, the assimilation of nitrogen may be thought of as a series of chemical transformations in which bacteria play a central part. The entire cycle operates as a steady-state, and might arbitrarily be constructed as shown in Figure 1. Arrows connecting successive steps in the diagram symbolize activities of living organisms, and represent processes known to occur. Since most of these are bacterial, the efficiency of nitrogen utilization depends largely upon a bacterial flora, which in turn requires a suitable environment. This relationship brings us again to the pond bottom which has become an inescapable factor. The

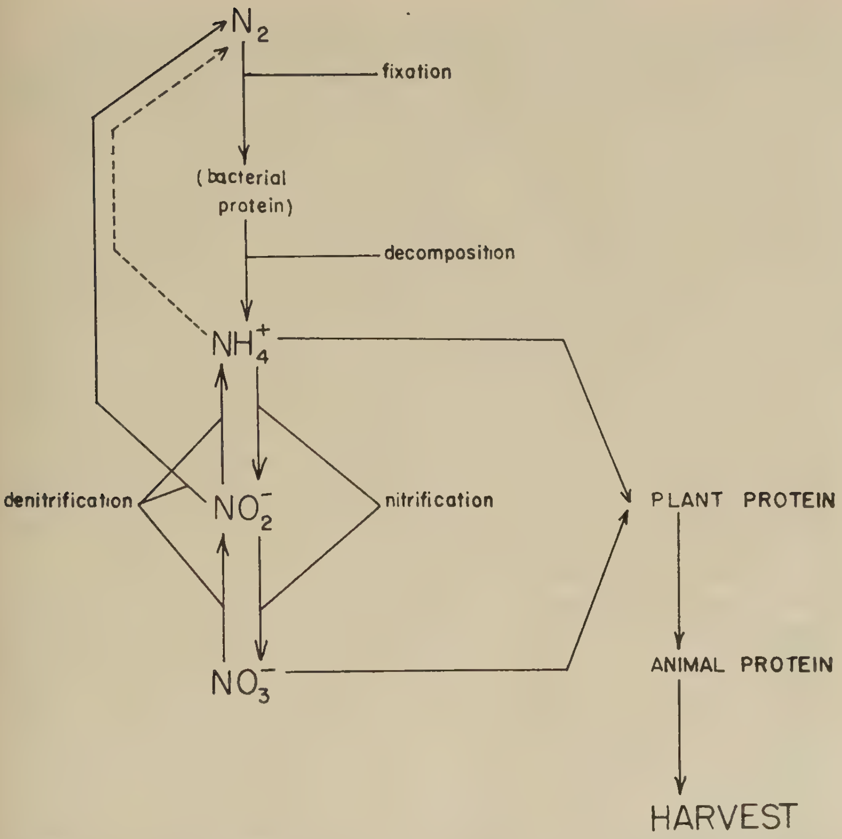
N_2
fixation
(bacterial protein)
decomposition
NH_4^+
denitrification
NO_2^-
nitrification
PLANT PROTEIN
ANIMAL PROTEIN
NO_3^-
HARVEST

FIGURE 1.—Proposed scheme of nitrogen utilization in a pond, including fixation by forms like *Azotobacter*. The dotted arrow indicates that ammonia inhibits nitrogen-fixation though it is not converted directly to atmospheric nitrogen.

whole question of nitrogen is set apart from the consideration of other fertilizers by the peculiarity that the pond is continuously in the presence of an unlimited supply of this element, *viz.*, the atmosphere. If Figure 1 accurately represents the facts, then the cycle of nitrogen utilization is internally limiting and does not depend upon the addition of nitrogen fertilizers. That is, in spite of interference by the addition of fertilizers, the system will tend to return to its previously established equilibrium, into which only a limited quantity of bound nitrogen is admissable.

We consider first nitrogen fixation. Lantzsch (1924) has shown that nitrogen-fixing bacteria are present in large numbers in pond soils, although not numerous in open water. Exemplified by Demoll (1925), most German culturists are convinced that bacterial fixation can be held accountable for most, if not all, of a pond's combined nitrogen supply. Accordingly, the conditions under which active forms (particularly *Azotobacter*) thrive are provided insofar as possible by appropriate management practice. Nitrogen is fixed by *Azotobacter* in culture only under strictly aerobic conditions; fixation is inhibited at pH below 5.6 and also in the presence of nitrogen furnished from a source other than the atmosphere (*e.g.* ammonium salts). Phosphorus must be supplied to the organisms, and is taken up from the medium more or less in proportion to the amount of nitrogen fixed (Stoklasa, 1911). Lantzsch (1924) observed that in ponds fertilized with phosphorus, *Azotobacter* penetrates the soil three times as far as in unfertilized ponds; this does not imply necessarily that *fixation* is increased, however, since the organisms can live normally without fixing any nitrogen. Certain genera (*Anabaena, Nostoc*) of Cyanophyceae are known to fix atmospheric nitrogen (De, 1939; Fogg, 1942) but these have not yet been considered by German workers. The assumption is implicit in all of this discussion that, given the proper organisms in a proper environment, significant quantities of nitrogen will be fixed. This need not be true, and indeed, no quantitative estimate of the annual production of autocthonous fixed nitrogen in a pond is available. The lack of research on that point is unfortunate; the subject fairly begs for further investigation.

After fixation, nitrogen is released from the original bacterial protoplasm and further transformed by other types of bacteria. In these transformed states it is available to the remainder of the biota. Surpluses of combined nitrogen cannot be stored by a system of this kind except as fish protein, and quantities not thus used are reduced by denitrifying bacteria and reconverted eventually to free nitrogen. So if the steady state is interrupted by the addition of already combined nitrogen (*e.g.* nitrate fertilizers), denitrification will be accelerated and nitrification and fixation retarded until equilibrium is re-established, and the net gain in nitrogen stored as fish protein will be slight—certainly not in proportion to the amount of fertilizer added.

This discussion assumes that small variations in the concentration levels of various forms of nitrogen are corrected immediately by accelerations or inhibitions of transformation rates. Such rate changes are dependent upon concentration fundamentally, but appear to be stimulated by variations on a rather gross level and as a result, take on a seasonal aspect (Domogalla and Fred, 1926; Fischer, 1916). It is nevertheless probable that the addition of large quantities of nitrate will stimulate denitrification (which proceeds freely throughout the pond in the open water). Demoll believed that this effect could be reduced if ammonium salts were used instead of nitrates, but he could not demonstrate a difference between the two experimentally. It is surprising that there also appeared to be no difference in the effect produced by the same quantity of nitrogen fertilizer applied in 1, 2, 20, and daily doses throughout one summer. He continued to venture that phosphorus is a guard against denitrification since it hastens growth processes in general and encourages more rapid inclusion of nitrogen in animal and plant proteins. It is somewhat difficult to distinguish cause from effect in a situation of this type, however. The whole matter is still far from clear. Walter and Nolte (1929) have summarized the objections to inorganic nitrogen fertilizers.

RELATION OF CARBON TO NITROGEN

When fertilization with nitrogen is practiced, the element is usually supplied in the form of easily obtainable organic materials. Many substances are used in this way, ranging from composted vegetable matter (Bugov, 1926) to manure, stable drainage, slaughterhouse waste, and municipal sewage. Organic fertilizers are widely used in the United States as well. These materials may take one of two paths around the trophic cycle of the pond. They may be broken down directly through the agency of microorganisms to soluble simple (inorganic) compounds which are then recirculated through autotrophic bacteria and green plants. Or they may be used as complex compounds (the cell substance of the primary heterotrophic bacteria involved in decomposition) as foods by higher forms (protozoa, animal plankton, . . .) and returned more rapidly to the fish crop. In the latter case, nitrogen in transferred more or less quantitatively from the fertilizer to the crop, even where the initial foodstuff is bacterial cell substance. Meehean (1933, 1935) has observed the operation of food chains of this kind, and it is likely that the "hay-infusion" effects seen in newly flooded reservoirs and meadows (high production of zooplankton crustaceans in the relative absence of phytoplankton) are the result of some such series of transformations. Einsele (in personal correspondence) described a scheme for rearing northern pike in hay-meadow dales flooded in spring after development of a heavy sod. Growth was unusually rapid and losses due to cannibalism were reduced. Here food was chiefly zooplankton. Of course, other food chains, beginning with autotrophic algae may also result in high production of zooplankton (Pauly, 1919).

Where nitrogen is transferred via complete decomposition (mineralization), the same allowance for losses due to denitrification must be made as with inorganic nitrogen. On the other hand, if we assume momentarily that fixation provides a significant quantity of nitrogen to the pond, then we see that one of the chief values of organic fertilizers lies in their carbohydrate content. In heavily stocked ponds where rooted aquatic plants are discouraged, the chief accumulators of carbon are the fish, which are later removed. Nitrogen fixation by *Azotobacter* must proceed in a substrate of carbohydrate materials, required both as a source of energy and as a constituent of bacterial protoplasm. This carbon is taken up with free nitrogen in fixed ratios (Waksman and Starkey, 1931). If readily useful carbohydrates are not available, fixation will stop. On this basis, Walter and Demoll criticised the use of high-nitrogen, low-carbon fertilizers (*e.g.* urea). Many pond soils have a low available carbohydrate content (cellulose decomposition results primarily in the formation of hemicelluloses which are very resistant to further bacterial degradation). Without reviewing and analyzing data from a great many sources, it is difficult to demonstrate that this system actually is in operation. Cottonseed or soybean meals (C/N=40) have been found to be unusually effective fertilizers (Embody and Sadler, 1934; Hogan, 1933; unpublished observations of Neess and Hasler at Madison, Wisconsin) applied either alone or in conjunction with phosphorus. High-nitrogen organic materials such as urea are generally such strong stimulants both to growth of rapidly reproducing algae and to processes of denitrification that applications of large amounts result in over-heavy plankton blooms and often in poisoning of fish from algal toxins and, under certain weather conditions, anoxia.

The use of municipal sewage as a fertilizer, or rather the use of fish ponds for purification of sewage, is a widespread practice, and cities as large as Munich dispose of most of their effluents in this manner. The large yields of rainbow trout and carp which result are very acceptable food in Germany and in other countries to which they are exported. Kisskalt and Ilzhöfer (1937) and Wundsch (1927) have described these methods in some detail.

THE PROBLEM OF RESEARCH IN POND FERTILIZATION

In common with many other studies which require simultaneous consideration of many variables, pond fertilization does not readily lend itself to neat or decisive experiments, particularly without careful statistical control. Any systematic method of interpreting results by taking into consideration natural variation and random errors has been used so seldom as to have had no significant effect on the quality of investigations up to the present time. Many conclusions based upon the great bulk of published European data would not well bear re-examination by rigorous statistical analysis. This statement implies no criticism of standards. However, the conclusion cannot be escaped that experimental work has not yet been quantitative enough. Improvement of experimental technique will not only be of distinct value from the theoretical point of view, but will make it far easier to apply findings in a practical way. Some of the methods which have been so thoroughly worked out for the design of agricultural field experiments may be applied almost directly to pond-fertilization investigations. An analysis of the extensive data now in the literature would undoubtedly be of value.

It has been difficult in all parts of limnology to discover an adequate criterion of production. The yield of fish after a season's growth and with uniform rate of planting has been used almost universally in Europe. Whereas this is the standard of most direct value to the fish-culturist (who is not particularly interested in other changes in his pond so long as they do not effect fish production adversely), it is not altogether satisfactory since certain other variables which have nothing to do with fertilization will ultimately effect the yield. For example, different species of fish will certainly not respond alike to particular fertilizers. Similarly, fish of the same species but of different genetic background will not respond the same. The German pond carp has the longest pedigree of a fish species anywhere in the world, and still a great deal of difficulty has been experienced in making individuals react uniformly. The useful criterion of production will have to be compounded of several measurements.

In general, caution must be observed in attaching too much importance to any single measurement. We have seen that the chemistry of pond water at isolated moments gives only the roughest indication of processes underway in the pond. Chemical data certainly cannot be translated directly into the arbitrary standards of "fertility" which have been used in the past. Similarly, cultures of algae grown in glass jars and in purified solutions do not adequately represent the algal flora of a pond. The pond flora, then, probably will not respond predictably to fertilizers applied in accordance with information gained solely from such experiments (see the notable non-correspondence between limiting concentrations of nutrients in Chu's cultures and limiting concentrations of the same in natural waters: Chu, 1943). In fact, the principle seems to hold that the smaller the body of water, the more aberrantly it behaves and the more difficult it is to understand (Gessner, 1932).

The great value of research in pond culture, outside of its place in general limnology, lies in its practical applications. It is perhaps unfortunate that this is true, since to make results easily accessible to everyone who might wish to use them, they must be stated in terms which are universally meaningful. This requirement has unquestionably reduced the methods of research to a level entirely inconsistent with the complexity of the materials with which it must deal. The subject matter of experiments has not been standardized. Ponds have differed widely in shape, size, soil, climate, . . . ; fertilizing materials have often been of unknown composition (sawdust, leaf-litter, manures, hay, grass-clippings, . . .). In addition, chemical and biological observations have been made inconsistently from place to place. It is not hard to believe that duplication of results from one research station, or even from one pond, to another has been possible only in rare instances (see the series of Walter's articles on fertilization experiments at Wielenbach).

At best, biological correlations between variables which are not closely related are inconclusive. Quantities like *amount of fertilizer applied* and *weight of fish produced* are easy to measure accurately, but the functional relationship between them is blurred by intervening processes. As the complexity of these intervening processes increases, the relationship becomes less definite, and may for all practical purposes disappear. But in pond fertilization, where there is no clear functional relationship between such variables as these, there is no practical knowledge to be gained. It is therefore not only necessary to be familiar with beginning and ending quantities, but to attack intervening processes as well. This attack can be made through a deeper understanding of the place of such subjects as colloid chemistry, microbiology, biochemistry, and thermodynamics of aquatic environments in pond fertilization.

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Part 11

Symposium on the Missouri River Basin

FLOOD CONTROL, NAVIGATION, AND IRRIGATION AND THEIR RELATION TO FISH AND GAME

SYMPOSIUM

MISSOURI RIVER BASIN FLOOD CONTROL, NAVIGATION, AND IRRIGATION AND THEIR RELATION TO FISH AND GAME

MR. HOFFMASTER: The subject we are to discuss has to do with about one-sixth of the nation. An organization of this kind, representing every state in the Union, the Dominion of Canada, and the Republic of Mexico, should be interested in the developments planned for the Missouri River basin. I have some knowledge of what the plans are; I have listened to reports and have talked to people about it—and I find some conflicting views. I am inclined to think there is some misunderstanding with regard to the plans for the handling of the development of that great productive basin. Therefore I thought it might be well to have the people who drew up and coordinated the program come before the group and tell you first-hand—briefly, because we have only the morning—what the plans are. General Pick and Mr. Sloan kindly consented to do that, and, as you know from the program, Dr. Cottam has come to talk about the aspects of the plan which have to do with fish and wildlife.

First on the program this morning is a gentleman who was born and educated in Virginia, adopted Alabama as his state, and I believe spent all his life in the army. During the last war he made a brilliant record by building 483 miles of road across Burma and India in about 15 months—and he has done a lot of other things, I know. General Pick is in charge of the Missouri Basin for the Corps of Engineers of the United States Army. He is also chairman of the Inter-Agency Committee, which consists of the governors of four states and a number of heads of important departments. From his name and nature I believe he is a great fellow to dig into his subject.

I take great pleasure in presenting to you General Pick.

GENERAL PICK: I feel a bit out of place here today; I feel that I am currently on the edge of our daily routine work in connection with the Missouri River basin. But I think it is time to draw into the center of the development all agencies and activities which are interested—vitally interested—and which will have a hand in this great development.

I said that I felt out of place here, but as I look over this group of men and women, I can see that you are outside people, not inside people. You are the people who do the work on the outside; and those are the people with whom we work all the time and who have an interest in this great development. I hope we shall live long enough to see it completed.

Now, I have a little paper prepared here which I will read to you. It doesn't amount to very much, but the spirit back of it I believe is good. If you understand that I think you will get what I want to leave with you.

RECREATIONAL FEATURES OF MISSOURI RIVER DEVELOPMENT PROGRAM

BRIGADIER-GENERAL LEWIS A. PICK
Corps of Engineers

Almost from the time this nation established its independence 150 years ago, the Corps of Engineers has had the traditional peace-time task of developing rivers and harbors for water-borne commerce.

In 1936 the Congress added a new assignment to its peace-time civil-works responsibilities—the control of floods. Flood-control studies and planning were just getting well under way when the war intervened with its drastic demands upon all our national skills and resources.

Now, as the nation moves ahead to meet the challenge of reconversion, we of the Corps of Engineers are resuming our peace-time duties and responsibilities. The 4-year interval of war has intensified some of these responsibilities and the need for action to meet the demands of public safety, progress, and economic prosperity.

It is to some of these problems, particularly river-basin development and control of water resources, that I dedicate my remarks today. I count it a privilege and an opportunity to meet with a group of people whose interests lie in similar channels. We of the Corps of Engineers welcome such opportunities for interchange of ideas and coordination of efforts in the interests of the people we serve.

The Flood Control Act of December 1944 substantially broadened the scope of duties and responsibilities of the Corps of Engineers. The Secretary of War and the Chief of Engineers were authorized "to construct, maintain and operate public park and recreational facilities in reservoir areas under the control of the War Department, and to permit the construction, maintenance and operation of such facilities by others."

We welcome that assignment. It paves the way for another forward step in the full, comprehensive, multiple-purpose development of the nation's watersheds.

When the Congress enacted this section of the 1944 Flood Control Act, it very properly had in mind the potential public benefits that would flow from the development of recreational areas around large reservoirs. It is readily apparent that the need for adequate recreational facilities has increased tremendously in our modern life. The trend is sharply upward.

This was a natural development growing out of the gradual change in the way we live; the shortening of the work week, increased family incomes and concentration of population. Proper rest and recreation doubtless have had and are having an appreciable effect upon our national health. Vacation trips and week-end outings now are within the reach of millions of our people who a generation or so ago had only restricted opportunities to enjoy them.

We Americans, with our comparatively recent heritage of pioneer life, are particularly endowed with a love of the out-of-doors. Those pursuits which were the life necessities of our forefathers—hunting, fishing, trapping, etc.,—now provide profitable employment of our newly found leisure time.

In the Missouri Basin today we have a great program under way for development of water resources. This program holds enormous possibilities for public enjoyment and recreation.

The 1944 Flood Control Act gives the Corps of Engineers authority to plan the development of immense new recreational areas in the watershed of the Missouri River.

While the primary purposes of the comprehensive plan approved by the Congress for the Missouri Basin are flood control, irrigation, hydroelectric power development, and navigation, the lawmakers did not stop there. They properly viewed river-basin development from an overall standpoint, including recreation and fish and wildlife conservation. The Missouri Basin holds an important place in the nation's wildlife picture. The northern part of the area constitutes the most important breeding section for migratory waterfowl in the United States.

But much of the Missouri Valley is semi-arid and lacking in the types of lakes and streams that encourage propagation of fish and wildlife. Therefore it is obvious that a vast water-storage system such as is now in the initial construction stage in the basin holds the promise of great development along these lines.

It has been estimated that 20 million people in the United States hunt and fish. They depend upon these sports for outdoor recreation. In pursuing these recreations, hunters and fishermen spend something like 2 billion dollars annually. They have a natural and proper interest in what is being done in the development of river-basin areas of the nation.

Now I am aware that there are some wildlife enthusiasts who are apprehensive that large multiple-purpose reservoirs may destroy wildlife habitat with resultant loss of fishing and hunting opportunities. I see no reason for such fears.

For every acre of presently existing habitat that may be lost by reservoir inundation, there will be created areas much larger in extent which can be made suitable for fish and game propagation.

I should like to emphasize that the comprehensive river-development program on which construction work is under way this year in the Missouri River is truly comprehensive in scope. It is not a restricted program which disregards any of the beneficial uses of the water resources of the basin.

The Corps of Engineers has construction work under way on six large reservoir projects in the Missouri Basin, including the Fort Peck Reservoir. And I can assure you today that careful consideration is being given to recreational facilities and possibilities for fish and game conservation at each of these projects.

These six reservoirs will have a combined shoreline of approximately 5,000 miles. They are located in areas which heretofore have offered very little in the form of water sports or fishing. Some of them are in semi-arid regions where annual rainfall measures from 14 to 20 inches and where the residents are compelled to travel hundreds of miles to find fishing and water sports.

Anyone familiar with the muddy Missouri River knows that it offers very little in its present state from a fishing and recreational standpoint, with the exception of waterfowl hunting in one season of the year. The large reservoirs on the main river and its important tributaries will form great lakes of clear water which will offer almost unlimited opportunities for boating, picnicking, fishing, swimming, and other sports.

Just a few weeks ago I made an inspection visit to the Fort Peck Reservoir on the Missouri River in Montana. This project, built by the Corps of Engineers, was completed in its main features in 1939. It has a storage capacity of 19 million acre-feet and forms a lake more than 150 miles long. Today the reservoir is almost filled. The water is clear. You can see down 6 or 7 feet. I was told that residents of the community and visitors are enjoying good trout fishing and are catching fine strings of walleyes, yellow perch, crappie, and other varieties of fish.

The Fort Peck District Engineer, Lieutenant-Colonel H. H. Roberts, and his staff, were at work on plans for the creation of recreational areas on the lake shore. At the same time the primary purposes for which the reservoir was built are being served. When I was there the first releases of water were being made over the spillway to test its efficiency. These tests were highly successful. Water also was being released, as required by the Congressional authorization, for navigation benefits downstream and 40,000 kilowatts of hydroelectric power were being produced for the use of the people of Montana. Ultimately it is planned to increase hydroelectric power production to 105,000 kilowatt-hours.

I found there a practical demonstration of what a large reservoir can do for the benefit of the people in many ways, including additional pleasure afforded by good fishing and added recreational opportunities.

The coordinated plan for control and utilization of the waters of the Missouri Basin provides for 105 reservoirs on the main stream and its tributaries. In addition, Congress directed that agricultural levees for flood protection be built along both sides of the Missouri from Sioux City to the mouth near St. Louis. And certain other local flood-protection works were included in the approved plan.

All of this was embodied in the Flood Control Act signed by the President in December 1944. The engineering foundation for this comprehensive plan was laid by the best engineering skill of the Corps of Engineers, the Bureau of Reclamation of the Department of the Interior, and other interested Federal agencies. Agencies specifically designated by the act to coordinate their related activities in the program are the Department of Agriculture and the Federal Power Commission.

Something over 14 months ago there was formed a basin agency to coordinate the activities of the several groups interested in the basin. It is known as the Missouri Basin Inter-Agency Committee. Serving on it are one representative from each of the four Federal agencies just named, and participating in all of its monthly meetings are the governors of four basin states. These governors were selected by the Missouri River States Committee composed of the governors of the 10 states lying wholly or partly in the Missouri Basin.

The Inter-Agency Committee serves not only as a coordinating body for Federal agencies, but it gives direct representation to all the states in the basin through their governors. It provides a democratic process which is responsive to the wishes of the people throughout the basin.

The Committee has honored me with the chairmanship this year and I can assure you that it is functioning effectively. The committee meetings provide a clearing house for exchange of ideas and for discussion and determination of problems that arise. It has provided and will continue to provide a medium through which officials of the Fish and Wildlife Service and other interested agencies can present their programs for integration into the overall plan.

I have just received word within the last few days that Mr. Sloan has been made a member of that committee, and I think rightly so.

The Committee had the pleasure last May at its meeting in Des Moines of hearing an interesting and instructive discussion of the plans of the Fish and Wildlife Service for development of areas around the reservoirs which we are building and will build later. That discussion was given by Mr. Rudolph Dieffenbach of Chicago, Chief of the Office of River Basin Studies, of the Fish and Wildlife Service.

It is the policy of the Missouri River Division of Corps of Engineers to contact other interested agencies at the beginning of a survey study or a definite project study. They are advised then of the project under consideration. After certain tentative determinations are made as to a reservoir location, height of dam, capacity, and other facts needed for intelligent discussion, these agencies are invited in for full discussion and cooperative planning.

On each of the reservoir projects of the Corps of Engineers, Federal and State fish and wildlife agencies have been consulted. Numerous conferences have been held between representatives of those agencies and the Corps of Engineers. On all these projects the Fish and Wildlife Service has been invited to make surveys and studies. In each case they have submitted or are preparing recommendations for our consideration.

Now I should like to say that in my opinion there has been some loose talk about certain wildlife activities in connection with the Missouri River basin development. I can assure you we never start planning a structure, a reservoir, or any work in the river which we think would be of interest to the fish and wildlife personnel, without immediately contacting the State and Federal groups and inviting them to make the study with us. There is talk going about the country that the fish and wildlife agencies are not considered. That is incorrect. The Bureau of Reclamation, the Corps of Engineers, the Federal Power Commission, the Department of Agriculture, working through the Inter-Agency Committee, issued a progress report in the early spring outlining every project that we contemplated undertaking under the authorization we have now for the Missouri River basin. That progress report was widely distributed —distributed to all Federal agencies and everybody else we thought would be interested in it. It showed definitely the status of each project—those that we were ready to go to work on; those that we had money for but had not been planned; and those that we were planning. We hope everybody now understands that we are going to carry out the works in accordance with the report that we issued to show you the order in which these projects would probably be taken up. State and Federal agencies throughout the entire basin, and in addition civic and political bodies participate in the planning. There is no reason in my opinion for anyone to say that this work is being carried on behind closed doors. Certainly, we don't want it carried on in that way.

Consistent with the primary purposes for which the large reservoirs were designed and approved by the Congress, every effort is being made to fit into our plans the suggestions and recommendations of the Fish and Wildlife Service. The desires of the various states and local communities also are given careful consideration.

Public Law 534, enacted December 22, 1944, which is the Flood Control Act, specifically provides that "no public use of any area to which this section applies shall be permitted which is inconsistent with the laws for protection of fish and game of the state in which such area is situated."

In all our planning relative to the Missouri Basin reservoirs we are giving consideration to the best methods of providing improved fishing, hunting, picnicking, and other recreational activities such as swimming and boating.

I am convinced that the plans now formulated, or being worked out, will greatly enhance the public benefit to be derived through greater recreational opportunities and the conservation of our fish and wildlife resources.

I think you will be interested in a brief summary of what we are doing in the Missouri Basin this year to control and develop water resources under the Congressional direction Congress allotted approximately $39,000,000 to the Corps of Engineers for basin projects this fiscal year. The Bureau of Reclamation received a comparable sum for its projects.

The funds of the Corps of Engineers already have been put to work. By August 1, some two weeks before the moratorium on Federal works expenditures, we had obligated all of our funds for the fiscal year. As I mentioned earlier, we have initiated construction this year on five major reservoirs in five states.

The largest of these is the Garrison Dam, 75 miles northwest of Bismarck, North Dakota. This dam will be the largest rolled, earth-fill structure of its kind in the world. It will impound 23 million acre-feet of water, exceeding the capacity of Fort Peck Reservoir by nearly 4 million acre-feet.

The dam will be over 2 miles in length and will have a maximum height of 210 feet. It will create a lake 200 miles long. It will provide water for irrigation, development of hydroelectric power, improvement of navigation on the Missouri River downstream, improved municipal water supply, and sanitation. And it offers immense opportunities for recreational development and propagation of fish and wildlife. We are planning for maximum use of these recreation and conservation possibilities. This reservoir alone will have a shoreline of some 1,700 miles.

We have let four contracts on the Garrison project. The east access highway is well along toward completion. Excellent progress is being made on an access railroad. A construction town has been laid out, graded, and a sewer system installed. Work is in progress on housing units for workmen and their families. Furthermore, work has started on a construction bridge across the river.

Downriver some 700 miles, initial construction work is going forward on the Fort Randall Reservoir. The dam site for this project is located on the Missouri River opposite old Fort Randall, about 60 miles west of Yankton.

This reservoir will have a storage capacity of slightly more than 6 million acre-feet. It will back up the river some 150 miles, creating another large lake with a shoreline some 1,400 miles in length. Located in an area where there are few clear streams or lakes, it can be made to afford fine fishing, hunting, and other recreational facilities. It will provide storage of water for flood control, navigation, hydroelectric power development, and conservation purposes.

We also have contracts let and work in progress on the Cherry Creek Reservoir, a smaller project, but extremely important as a flood-protection measure to the City of Denver.

Earth is being moved for initial stages of the construction of the Harlan County Dam on the Republican River in south-central Nebraska. The Harlan County project is designed to provide flood protection for the Republican Valley and to supply water for irrigation of 90,000 acres of land downstream from the dam. The contract also has been let for completion of the Kanopolis Dam on the Smoky Hill River in Kansas, another important flood-control project.

In addition we are building a flood-wall to protect the central industrial district at Kansas City and a levee to protect the Kansas City Municipal Airport and the North Kansas City industrial area. We are at work on levees for the protection of Omaha, Nebraska, and Council Bluffs, Iowa, and have several other local flood-protection, and a number of river-channel-control, jobs under construction.

While we are making a substantial start on the overall plan for the Missouri Basin this year, the whole plan will require from 10 to 15 years to complete, as Congressional appropriations are made available. There is ample time for continued planning and development of recreational values at each of the reservoir projects.

We welcome the continued cooperation and advice of the International Association, the American Fisheries Society, the Izaak Walton League, and similar organizations, as well as the Federal and State agencies which are equipped to assist us in making the best possible use of the 5,000 miles of shoreline along the reservoirs now under construction and others to come later. The enhancement of wildlife values in these reservoir areas will be great. Migratory waterfowl will find refuge and rest in these waters and they will provide fishermen and hunters with many profitable hours of sport and relaxation.

A new era of development is opening up in the Missouri Basin. The program on which we are at work not only will put an end to destructive floods which have harassed and held back progress and expansion, but will contribute substantially to the development of mineral resources and increased prosperity on the farms and in the cities.

This is a truly comprehensive basin plan which recognizes the need for fullest utilization of water resources for the broadest public benefits.

In summary, I wish to emphasize again that the Corps of Engineers recognizes fully the value and importance of fish and wildlife resources in the basin, also that the Inter-Agency Committee and the other Federal agencies recognize these values and are interested in them, and interested in seeing that they are provided for. Recreation has become a significant factor in our national economy and our social well-being. We of the Corps of Engineers, with the help of such organizations as yours and your constituted Federal and State agencies, expect to make a large contribution to this growing national need.

Mr. Hoffmaster: For want of time, we are dispensing with the provision which is made on the program for discusson leaders, but we are not closing the meeting to discussion. Any of you who wish to ask a question or to request that the General develop any particular point that he touched on in his paper are welcome to do so. I know it is an involved subject, and perhaps we could keep him busy the rest of the morning, but about 15 minutes is all we can give to it. Any of you who are interested in asking questions of the General please confine them to the discussion of the subject as treated here.

Mr. Willard (Minnesota): How are these projects financed as between the Federal government and the local sponsors and interests?

General Pick: It is provided in the law that these projects will be financed by the Federal government. The Fort Peck Dam, for example, was built by the Federal government at Federal expense. Neither the state nor any local political or civic body contributed to the cost of construction. The other projects which we have going on at this time, so far as reservoirs are concerned, are the same. With respect to agricultural levees on the river from Sioux City down, the 1936 Flood Control Act provides that the local interests shall furnish the rights of way for the levees and local protection works, and maintain the projects after they are completed and turned over to them.

Mr. Maurek (North Dakota): General Pick referred to the Garrison Dam in North Dakota. He says that it is for flood control mainly; is that right?

General Pick: No; I would not say mainly—it is a multiple-purpose structure. We expect to develop a lot of power there, and we expect to provide a large block of water which some day Mr. Sloan may use for irrigation. He is studying plans now. In addition, we are going to release water to provide a supplemental flow to the stream at low water for navigation, water supply, and sanitation, all the way down to the mouth of the Missouri River. Furthermore, the water that we hold up and stock in this large reservoir will be water which will not go downstream and cause damage by floods.

Mr. Maurek: But the dam will be subject to radical water-level fluctuations.

General Pick: The dam will be subject to fluctuations, but they will not be so radical. In a reservoir with a shoreline of 1,900 miles the amount of water that we release for power will be, having regard to ultimate installed capacity, something less than 1,500 second-feet; therefore I do not believe the fluctuations will be violent.

Mr. Kaupanger (Minnesota): This particular project, as I understand it, is for the purpose of navigation, flood control, and hydroelectric power; isn't that true?

General Pick: Yes, and irrigation, and fish and wildlife activities.

Mr. Kaupanger: That being so, can you point to one project in the United States that has been built in the interests of navigation, flood control, and irrigation that has been beneficial to wildlife, recreation, and fish?

General Pick: Fort Peck.

Mr. Kaupanger: That remains to be proven.

General Peck: Have you been out to Fort Peck, sir?

Mr. Kaupanger: No.

General Pick: I will invite you to go out there and fish.

Mr. Kaupanger: You made one statement I agree with. You said that this is a democratic process. I concur.

Mr. Evans (Minnesota): What provision is there in the Flood Control Act for general watershed erosion control?

General Pick: It is provided for in the Flood Control Act. I did not go into the soil-conservation problem; I was sticking pretty closely to recreation and related subjects. Soil conservation is an important part of this program. Tremendous strides are being made at the present time in every state in the Missouri Basin in putting into effect a soil-conservation program. Yesterday in Omaha there was a soil-conservation meeting at which representatives from all parts of the United States were showing people how to build terraces, and they were competing with each other as to how fast and how well they could build them. Soil conservation is, in my opinion, one of the most important activities in connection with this development. We have two things to consider out here: one is water, and the other is land, and they can not be separated. The soil must be protected. If the soil is properly and adequately protected the water will run off the land clear; and if it does so, our reservoirs will not have to be filled with that top soil which should be retained on the land.

Mr. Westerman (Michigan): What will be the fluctuation in feet in operation of the dam?

General Pick: I can not give you that figure now, because our operation studies have not been completed by any means. We have not worked out the plans, which are very complicated and must provide for many activities. Our great fluctuations—and I think Mr. Sloan will bear me out in this—will come only during periods such as we had in the thirties, when there were several years of more or less dry weather. We have provided enough storage in all these reservoirs to take care of a drought period like that. That is when you get your big fluctuation; that is when you need the water most. I do not know whether I have answered your question or not, sir.

Mr. Feast (Colorado): In answer to a question as to whether any project of the kind had been planned and operated in the interests of fish and wildlife, you mentioned Fort Peck. From my experience and observation I can speak of two that are not in the interests of wildlife. One is the operation of the Mississippi pools; the other, in my own state, is the Cadoa Dam. Both of these projects, in my opinion, are not in the interests of wildlife, and such interests were not given primary consideration in their construction.

General Pick: Gentlemen, we must arrive at a scheme of operation of these large projects which will bring to the people the greatest benefits. It would be a miracle, I think, if Mr. Sloan and I could sit down now, before these projects are built, and devise a scheme of operation which would be perfect in all its elements. If the reservoirs you speak of have not been operated to produce the greatest benefits to the largest number of people, there is nothing to prevent a workable scheme being devised to correct that. It even took the Lord 6 days to create the world. You cannot expect human beings to figure out perfect solutions to all our earthly problems overnight.

Let me give you an example. With the 1,900 miles of shoreline on this reservoir, we would be foolish to try to plan the ultimate development of the whole area at one fell swoop. We have 50 to 100 years to complete our program. Why not let us work on a sane and sound basis and go forward as our experience grows. Perhaps if we were diverting a large block of water out of Fort Peck for irrigation purposes, Fort Peck might be included among those to which you refer as not being operated properly. We have to consider the needs of all people, and we have to try to work out a solution which will give them all the greatest possible benefit from these structures. The people of the United States are putting up the money to build them.

Mr. Kendall (Oklahoma): I do not want to ask the General a question; I want to come to his assistance. In the State of Oklahoma there is Lake Texoma. Below the dam on the Red and Washita rivers I have seen with my own eyes vessels brought from New Orleans and placed in the lake. Navigation below the dam is better than it ever was before the lake was impounded. The building of the Denison Reservoir created abundant bass fishing where formerly there was none, and game has benefited too.

Mr. Hoffmaster: General, do you wish to comment on that?

General Pick: No, because I know it is true.

Mr. Lowe (North Dakota): Was the Conservation Department of the State of North Dakota ever invited to participate in the original planning of the Garrison Dam?

General Pick: I do not know whether you got an invitation or not. I know that your two Congressmen, and your two Senators, and Governor Moses, and the Water Conservation Board, which I have understood to represent the State in all matters of water use in the State, were vitally interested in the project and assisted me personally in working it out.

Mr. Lowe: I happen to know we were not invited.

General Pick: You were not invited to what?

Mr. Lowe: To participate in the plans for conservation of wildlife, as you said was done when these plans were in the making.

General Pick: I thought your Water Conservation Board dealt with all water matters for the State.

Mr. Lowe: They have nothing to do with fish and wildlife.

General Pick: The Governor has.

Mr. Lowe: Another question. You said, I think, that you had plans for the replacement of any values that might be lost. What plans have you made for replacement of the deer and pheasant habitat in the areas that will be inundated?

General Pick: The shoreline around the lake will reach the wooded area all along the west side, which I think will give them plenty of cover, if that is what you are talking about. I think you will have more food for them.

Mr. Lowe: You said it took the Lord 6 days to create the earth. It took nature a good deal longer than that to create the Missouri Valley. Whatever is destroyed in the Missouri Valley will not be replaced in the lifetime of anyone here. The plantings that are necessary, as I see it, can not be grown along these shorelines.

General Pick: I cannot agree with that, because I find that plenty of trees can be grown around the lakes. We have a nursery below Fort Peck dam, and the trees grew so fast I had to have them cut down.

Mr. Lowe: The mere growth of trees, of course, does not create wildlife habitat. I was just wondering, from what you said, if plans were complete for the replacement of these values.

General Pick: I have said that the plans are not complete; we have not had time to complete them, and I do not think we should try to complete them now so far as fish and wildlife are concerned around that 1,700 miles of shoreline. I think we should leave the plans sufficiently open to enable us to change them from time to time, if money becomes available to do something more comprehensive—and if the population in that section of the country becomes more stable, which I think will happen.

Mr. Lowe: Now we are getting somewhere. I would hate to see this group believe that plans are complete, because, as I see it, very little planning has been done to create fish and wildlife values.

General Pick: You are protesting the building of the Garrison Dam; it that it?

Mr. Lowe: All I am asking is that adequate provision be made for replacement of the fish and wildlife values that you destroy.

General Pick: What can the State do to help out?

Mr. Lowe: The State can furnish ideas along that line.

General Pick: It is a 50-year program.

Mr. Lowe: You have invited the Fish and Wildlife Service to assist you. We in turn are furnishing data which the Fish and Wildlife Service is using. If the work of the three groups can be coordinated and brought together we will get along all right.

General Pick: Have you talked to the District Engineer at Bismarck, who is building the project?

Mr. Lowe: No, but we know what is going on.

General Pick: I suggest you talk to him about it.

Mr. Williams (California): Although we are on the other side of the Continental Divide, once in a while we in California rub shoulders with the Army Engineers. I wish we had General Pick over there because I believe we could make medicine with him a little better than we do with the men who are there.

General Pick: Thank you very much, sir.

Mr. Williams: I think he is cognizant of the fact that there are natural values in wildlife and fish that probably were not considered when they were building the Central Valley project in California.

General Pick: In defense of the people who built those projects let me say this. It was not until 1944 that they had any authority to give vital consideration to these particular aspects of the problem.

Mr. Williams: We hope we have talked them out of one dam at Table Mountain, which of course would destroy the salmon run, which is valued at a number of million dollars a year. The salmon was not given due consideration at the time.

General Pick: I can not speak for the people on the other side of the mountains, but I can speak for those in the Missouri Valley. I hope you all realize we are vitally interested in your problem. We are working toward developing the maximum benefits not only for flood control and irrigation, but also for wildlife resources. If I can leave that thought with you and lead you to understand that we want you to work with us, I shall be happy. Thank you very much.

Mr. Hoffmaster: I am terribly sorry we have to end the discussion. General, we thank you very kindly for coming here and talking to us. I am sure everyone present has a better understanding of what the developments in the Missouri Basin mean.

Last July Mr. Julius Krug, Secretary of the Interior, was in Michigan. I had a chance to talk to him about our proposed plan of discussing the development of the Missouri River basin at this meeting. I asked him to join us; I thought it would do even a Secretary of the Interior good to meet with you people and with the General and Mr. Sloan. He then told me he could not be here, but that Mr. Sloan was the proper person to present his Department's side of the case.

Mr. Sloan is a westerner, but by adoption. He was born in Illinois, and when he was very young he went to Montana and was educated there. I believe it was somewhere in the west he started up a business in engineering. I am informed that he has interested himself only in drainage and irrigation engineering. For years he was in private practice, which was interrupted to some extent by the first World War; then he came back and went into the engineering business—irrigation and navigation. In 1935 he joined the Bureau of Reclamation. I am informed that he was made Chairman of the Missouri Basin Field Committee of the Department of the Interior in recognition of the good work he had done in the furtherance of the plan for the development in this valley.

I have much pleasure in presenting to you Mr. William G. Sloan.

PROGRAM AND POLICIES OF THE UNITED STATES BUREAU OF RECLAMATION

WILLIAM G. SLOAN

Assistant Regional Director, Bureau of Reclamation

As an engineer I feel like a fish out of water. I am not accustomed to explaining the Missouri River program to such a group as this. I did my best to avoid appearing before you, but it seems I was unsuccessful. Now that I am here and have heard something of what has gone on, I am glad I came.

The Bureau of Reclamation for the past 40 years has been receiving adverse criticism from many groups such as yours. We have seldom stood up in our own defense. I think we are going to do that from now on.

I want to say first that I plead guilty to having some part in an attempt to build an empire. The Missouri River plan is such an attempt. When fully accomplished the results will be equal to the addition of another state to the Union. It will reverse economic trends in the Missouri River basin. The plan was born of a controversy and it is a compromise among many interests in the basin. It was born of a controversy between the jurisdiction of two departments of the Federal Government—the Corps of Engineers and the Bureau of Reclamation of the Department of the Interior. Why did the controversy arise? The Corps of Engineers, as General Pick has told you, for years has had jurisdiction over the development of rivers, harbors, and navigation and more recently of flood-control projects. The Bureau of Reclamation since 1902 when "Teddy" Roosevelt—the father of conservation in this country—created it has had jurisdiction over the development of the water resources of the West for irrigation and power production. In the early days of reclamation we worked our problems out piece by piece, one project at a time. We did not foresee in the early days the bigger problems that were bound to arise in coordinated development.

Water, as you know, is the same as cash money to the people of the West. An acre-foot of water is always considered as so much money, and count is kept of the water that we have in reservoirs just the same as you keep a record of money in the bank. It is doled out in the same way, and is paid for, acre-foot by acre-foot. Water is the life-blood of the West. Water put upon the land is the solid foundation upon which the entire economy of the West is built. Therefore, if I appear to be somewhat prejudiced when I talk about the utilization of the water resources of the West, and perhaps prejudiced on the side of using it for the production of crops, I hope you will bear with me, because it is in my blood, and I hope it will never get out of it.

I am not unmindful of course of all the other uses of water. I will, however, put the value of water in the western part of the Missouri Basin for irrigation far above its value for any other purpose except domestic use; and I am speaking to you from that viewpoint.

As I said before, this Missouri River plan was a compromise, and it arose out of a controversy. Why? The jurisdiction of two departments of government came into conflict. Westerners, jealous of their water rights, could foresee developments in the lower part of the basin which would preclude their use of water for irrigation. They were fearful that projects would be developed on the lower river which would require the use of so much water that little of it would be left for irrigation in the upper part of the basin.

We found it necessary to coordinate the plans for the upper and lower parts of the basin, and they were coordinated. This Missouri River plan is the compromise that resulted. Primarily, it was a compromise between navigation and irrigation; but incidentally it was a compromise on all the other uses of water. You do not realize what could happen in the use of water in the Missouri River if one agency or one use of water should be allowed to go unhampered, and if the river were developed only for one particular use. The most drastic thing that could happen if irrigationists were allowed to go their way and develop their use of water to the ultimate would be that the lower Missouri would be dry most of the time. That could happen.

This plan, then, is a compromise. For a long time the use of water for navigation has been a primary right in the United States, a right given by the Constitution. When the western states were organized the use of water for irrigation also became a primary right. But always the original concept that the use of water for navigation had priority over the use of water for irrigation stood between us. Under this concept the people in the upper part of the basin would have been prohibited from making further irrigation developments, which would mean stagnation of their economy. They rose up in arms and said, "We must have our place in the sun." As a result we have a compromise plan that is going to benefit all interests.

General Pick has told you something about the general features of the plan. In reality, it is a plan to control, conserve, and use the entire water resources of the Missouri River basin—not for any one purpose to the exclusion of others, but looking to a balanced use for every purpose. There are people who say that we have not gone far enough; that the plan should have been expanded. We could irrigate an additional 3 or 4 million acres of land, yes, and we could have made the Missouri River generally more desirable for navigation at the expense of some other use. We could have designed this plan to develop to the ultimate all the possible power potentials of the Missouri River, and we could have designed it solely for the purpose of propagating fish and wildlife. But that is not the plan. It is a compromise plan, and we think that the interests of every user of water have been adequately taken care of so far as our limited vision at this time will permit.

I said the development of the Missouri River would add a new state to the Union. We estimate that the increased population in the Missouri Basin resulting from the development of this plan will be in the neighborhood of 600,000 people. It will change the agricultural economy of the Great Plains. Agriculture on the great northern plains is more precarious than in any other part of the entire United States; it is a gamble. We hope to make agriculture more stable. We estimate that the increase in crops to be produced with this development will aggregate more than $30,000,000 per year. Additional farms will be furnished for more than 60,000 people. Values will increase. The live-stock industry will be stabilized. I could continue for a long time enumerating the reasons why we plead guilty of an attempt to build an empire. We want to reverse the trends of decreasing population, larger farms, fewer people. This middle section of the Missouri River basin provided the least during the last war of any of the war activities. During the great period of drought in 1930–40 the Federal government poured into that area in relief funds over three-quarters of the amount of money necessary to build this entire project.

We are not apologizing, therefore, for this attempt to build an empire. We are going to exert every possible effort to develop this empire as fast as possible. But in so doing we do not expect to ride roughshod over other interests in the basin. The primary purposes of the projects are flood control for the lower valley, navigation for the lower valley, irrigation for the upper valley, power development in all regions, and all the other incidental benefits that must come from the proper use of the water. I have not spoken particularly about fish and wildlife and the part that they play in it, but I will do so later.

I should like to discuss briefly the matter of financing the work in the Missouri Valley. The General was a bit reluctant to talk fully on that point. I am going to say a little more, because I think it is essential that you understand some of the financial considerations involved in this project.

I mentioned earlier that the Corps of Engineers and the Bureau of Reclamation have entirely different jurisdictions. Out of these differences have grown the various Federal policies in the development of a project such as this. It has always been the custom for flood-control and navigation projects to be financed entirely by the Federal treasury. It has always been the custom in the reclamation of arid lands for the settlers themselves to pay the cost of the works. That was the initial concept on which the operations of Bureau of Reclamation were based. In the early days the farmers contracted to repay and did repay to the Federal government the entire cost of works constructed to put water on their land. But as time went on, the easier, low-cost projects having been built, it became increasingly difficult to build a project within the means of the individual settler. Furthermore, we discovered then that the benefits of these projects did not accrue to the benefit of the individual farmer alone. Over 50 percent of the money that went into a project was spent in the East. The towns adjoining the project increased in population. Our statistics show that for every man that was placed on a farm, two men moved to the adjoining towns and cities. The economic benefits from developments spread out beyond the limits of the projects and beyond the limits of the state to the nation as a whole. I could prove to you that the actual benefits were multiplied at least several times over the original investment in the projects.

Reclamation in the West has been slow, and it has been increasingly difficult to obtain money for development, simply because the people in the East do not understand the problem and do not care to share the expense. They have been perfectly willing to help pay for navigation and flood control, but in the eastern states and some of the southern states they could not see any benefit from the expenditure of Federal funds in the West. Reclamation projects did not have a universal appeal perhaps to congressmen and senators. Therefore we have had to fight for every dollar of expenditure that is made for reclamation in the West.

Coming back to the financing of this Missouri River program— on a pre-war basis the total estimated cost was something like $1,600,000,000. Much of this amount can later be recovered for the Federal treasury. The irrigators who benefit are expected to repay to the Federal Government and will contract to repay over a period of 40 years, more than $248,000,000. We have estimated that the repayment to the Federal government in net power revenues from the power projects built incidental to the other works will return an additional $450,000,000 of the cost of the project. In addition, revenues estimated at $50,000,000 will be obtained from the furnishing of water supplies to many of the towns. Thus probably 60 percent of the entire cost of this project will be repaid to the Federal Government—I think people ought to understand that— and the biggest part of it comes out of the pockets of the people in the West who are definitely benefited by the project.

It is vastly different from many of the projects that have been constructed in the eastern states, where the East gets all the benefits and the westerners have been taxed for their full share of the cost.

Now I am going to come to some of the features that are of particular interest to your organizations. In the early days of reclamation the projects were built by engineers. They were not all-around men. We did not realize that in bulding all these reservoirs we might have a profound effect upon the fish and wildlife of the territory. If we made mistakes, we made them through ignorance, and because of the limitation of our expenditures by congressional action. We are fast on the way to eliminating these defects in our original plan. We are still largely ignorant as to what should be done. We are learning as fast as we can. The planning of those features of the projects that concern fish and wildlife we are leaving now to the Fish and Wildlife Service, which is a brother agency in the Department of the Interior. We know our own limitations.

Our appropriation for the Missouri Basin from the Bureau of Reclamation is a lump sum, and that lump sum is again allocated by the Secretary of the Interior to the various projects and the various agencies in the Department. This last year $300,000 were set aside to the Fish and Wildlife Service for the particular purpose of studying the effect of each of the reservoirs upon fish or wildlife. Each year as we get those lump-sum appropriations sufficient money will be allotted to the Service to assure that fish and wildlife will receive proper consideration in the overall plan.

It might surprise you to know that of some seven or eight reports that have been made so far on the reservoirs that we propose to build or have already started, not one has been unfavorable in its appraisal of benefits to fish and wildlife in the construction of the reservoir. We do some damage, of course, but according to the valuation of Fish and Wildlife Service experts the benefits are greater than the damage. They have suggested changes in regulatory works which we are attempting to adopt. We are making every effort to understand thoroughly the problem they present to us, and we are trying to indicate to them our viewpoint also, so that out of mutual understanding will come more intelligent and more effective coordination in the use of the reservoirs for all the purposes which they should serve.

Now, I am a sportsman; I was reared in the West and have lived in the Rocky Mountains all my life. Each year I carry three or four fishing licenses so that I can fish in each of the states in which I work. I know something about your problems. I deplore as much as anybody else the fact that fishing is not as good as it used to be. I do not know why it is; I have not yet found the answer from any of the fish and wildlife people, or learned how we can bring good fishing back. Maybe fishing was not as good as I thought it was in my youth; perhaps my skill is not as great as it used to be. I do know, however, that I do not catch as many fish as I did in my youth.

During the last Congress a bill was passed, with the approval of both the Fish and Wildlife Service and the Bureau of Reclamation, which now makes it mandatory for the Bureau of Reclamation to include in a report on any project an estimate on its effects upon fish and wildlife and a statement of measures desirable for the development of those resources. Strange to say, that bill provides that any expenditures for the development of fish and wildlife resources shall be included in the cost of the project and shall be considered as non-reimbursable to the Federal government. But we have given you a favored position now, and we are working your plans into our structures and into our projects so that there may be improvement in the fish and wildlife population of the area, at the expense of the Federal government and everybody in the country. But we are glad to do that, to avoid some of this criticism that has been directed at us from time to time. I thing we are beginning to learn something about the requirements of fish and wildlife.

At the beginning of this talk I said that we plead guilty to building an empire. We are growing tired of certain criticisms. We have never struck back before. We hope that with a proper spirit of cooperation the plan for the Missouri Basin can be worked out to the satisfaction of everyone concerned. But we cannot succeed if you continue to hold the idea which is incorporated in an editorial, published in the journal of an organization affiliated in some way at least with your own. It reads as follows: "We stick to our original premise that empire building is bad. Giving these federal agencies a chance to build and grow more rapacious is too serious to be ignored." With that viewpoint there can be no cooperation. I hope it does not express the view of your organization. I know it does not; but this is the type of thing that is being published. We are tired of this sort of criticism. Don't blame us for everything that has happened. With willing cooperation and tolerance and more intelligent thinking on these problems by your own people and our own, I am sure that this great Missouri Basin plan can be worked out to the benefit of everyone concerned.

MR. HOFFMASTER: I have a feeling that Mr. Sloan is going to get something out of this meeting. He should have learned by now that in some instances he cannot have his own way. You will recall he said he did everything he could to avoid coming here. I am glad he failed in that respect. It was grand of you to come, Mr. Sloan, and we appreciate your fine presentation.

DR. GOWANLOCH (Louisiana): I should like to ask Mr. Sloan one question. We are very deeply interested in the Missouri Basin, strange as it may seem. We can identify, for instance, right in New Orleans, silt that came from the Yellowstone River. That is why we are interested in such a project as this. It is splendid work; but I should like to know one thing. Has the authorization been made for the construction of this project?

MR. SLOAN: The entire project has been approved by Congress. Authorization has been made, partly to carry out the initial stages of the project, for an appropriation of a total of $350,000,000 each for the Corps of Engineers and the Bureau of Reclamation. In other words the amount of $700,000,000 has been authorized for appropriation. Now, that does not mean that the money is actually appropriated, but each year as the appropriation bills come up amounts can be made available up to that limit. When the limit is reached, the authorization probably will be increased.

MR. BARKER (New Mexico): What Mr. Sloan has said about water being the lifeblood of the country in the west may be said with even greater truth about New Mexico than about some of the states further north. I cannot imagine any project that would involve the impoundment of water in that State the benefits of which would not far exceed the destruction of wildlife values. I think we have no quarrel at all with respect to the proposed program for further development in those states.

However, I want to ask Mr. Sloan this question. Will it be possible in the future so to adjust the operational plans of projects now existing as to give just a little more consideration to the fish life in some of our irrigation reservoirs? I refer in particular to the fact that some of our irrigation reservoirs now are drawn down to the very minimum, sometimes completely drained, with a resultant loss of fish in the reservoir. A few years ago Lake McMillan was completely drained, and hundreds of tons of fish were killed— which of course was an economic as well as a recreational loss. It was drained so as to give that last little acre-foot of water in the lake to the farmers on the project in order that they might grow more cotton at a time when they were being paid for not raising cotton. That, however, is all water over the dam—or out of the reservoir, I should say, because owing to silt conditions, Lake McMillan no longer serves as a reservoir of any values.

A case in point is the Alamogordo Reservoir in the central part of the state near Fort Sumner. It consists of 6.500 surface acres when full, but when it is drained down, as it is once or twice each year, to a minimum of 300 acres, the possibility of maintaining fish is virtually destroyed. I have asked the local engineers to maintain in that reservoir not less than 1,000 or 1,500 surface acres. Isn't it possible that some adjustment in operational plans might be made which would recognize these values in reservoirs now existing?

Mr. Sloan: You must realize of course that the Bureau of Reclamation has not built all the reservoirs in the west. We have built only about 10 percent of them, I think; the rest have been built by private interests. For the past 10 years it has been the policy of the Bureau of Reclamation that no reservoir shall be built or designed so that it can be completely drained. We have had quite an argument as to how much water should be left in a reservoir that could not be drained out. A thousand acre-feet of water in a reservoir costs a lot of money. We think the way is clear now so that we can increase the permanent pool to any desirable or practicable limit, because the cost of that pool can be charged off into the total cost of the project and will not have to be repaid by the settlers. The tendency in most of the private reservoirs when a dry year comes along and water gets scarce is to demand that the last drop be extracted from the reservoir. To avoid that demand we are purposely building the reservoirs with a high outlet so that they cannot be drained.

Mr. Barker: May I make one comment. A high outlet was provided for in the reservoir I have spoken about, but siltation has wiped it out entirely so that after a period of 10 years of operation it can now be drained.

Mr. Hoffmaster: Again, Mr. Sloan, may I say it was good of you to come, whether you wanted to or not, and we thank you.

Dr. Van Oosten, the President of the American Fisheries Society, will present the next speaker.

Dr. Van Oosten: The next speaker is well known among us. Dr. Clarence Cottam was recently appointed Assistant Director of the Fish and Wildlife Service. He has been associated with this Service and the former Bureau of Biological Survey since 1929. His biological assignments have covered a wide variety of subjects. He has carried on intensive investigations in economic ornithology and mammalogy, field research on management of waterfowl, upland game, control of injurious mammals and birds, and on marsh ecology, and has engaged in the coordination of wildlife conservation with other land and water uses. In 1944 he was appointed a coordinating and liaison officer for the Service in the field of wildlife conservation and management in connection with other land-use agencies, particularly the Bureau of Reclamation, the Corps of Engineers, the Tennessee Valley Authority and other federal and state agencies. Dr. Cottam therefore is eminently qualified to discuss the subject assigned to him—the effects of impoundments on fish and game.

Dr. Cottam: I feel that this is a propitious occasion when representatives of various interests—wildlife, reclamation, dam construction—meet to consider and discuss their common problems. I can still remember the time when our discussions were not so free and so amicable; and this I believe points to a happier future. Having had a little experience with engineering problems, though not an engineer myself, I must confess that at times I have been as impatient as Mr. Sloan indicated he was with the wildlife people with respect to some of their criticisms. Perhaps part of the reason for that impatience was, as the General pointed out, that $39,000,000 were allocated for dam construction each to the Army Engineers and the Reclamation Service, and $300,000 for wildlife.

If I may express a personal opinion—and incidentally I am a westerner; I was born and raised on a farm—while I know that water is the lifeblood of the west, water is also the lifeblood of wildlife. Wildlife has value in the west and elsewhere; therefore I want to suggest that the values of water can be measured more than just in acre-feet or kilowatt hours. There are many other values. It is true that man cannot live by bread alone. I hope we shall all take seriously the General's exhortation to us, namely, that the wildlife people be on their guard. I think that was an appropriate suggestion; it was given honestly, and I trust we shall follow it.

I am glad to have the opportunity of presenting some thoughts as to the relationship wildlife bears to the proposed Missouri Valley development. I want to correct one impression which was left by the last speaker, that he and his Corps of Engineers gave us the right to come in. So far as I am concerned he did not, and the Corps of Engineers did not; the American people did it, and of them we are a part. We are merely considering all interests. We want fish and wildlife to be considered equitably according to its merits, just as every other interest is considered—the greatest good to the greatest number. Therefore I cannot subscribe to the notion that irrigation must come first under all conditions. I know of many instances in which wildlife values far exceed the irrigation value in local areas. Often, of course, irrigation is predominant and must be given first consideration. But there are other situations in which irrigation, flood control, navigation, and power need not and should not receive first consideration.

Because of the limited time available I think I had better follow closely the text which I have prepared; so if you will pardon me I will read this; I can thus give it more quickly and more succinctly.

MISSOURI RIVER BASIN DEVELOPMENT AND ITS EFFECTS ON FISH AND WILDLIFE

Clarence Cottam

Assistant Director United States Fish and Wildlife Service

Importance of These Resources

Hunting and fishing represent America's most popular pastime. These are sports in which no fewer than 20 millions of our citizens participate. The popularity of hunting and fishing has been increasing constantly, and we may be sure that the present trend for increased leisure time and a higher standard of living will cause still more men and women to turn to these activities. Immediately after World War I, the sale of hunting and fishing licenses jumped 30 percent. Similarly, within the last 2 years, owing perhaps to the war-time experience in outdoor living and increased familiarity with firearms, the hunting and fishing pressure has already risen 40 to 50 percent. Polling returned veterans, the American Legion Magazine found that 69 percent chose hunting as their favorite recreation and 62 percent planned to go fishing; whereas baseball, motorboating, golfing, sailing, basketball, and riding were favored among 43, 30, 23, 11, 4 and 2 percent, respectively.

Our 20 millions of people who indulge in hunting and fishing spend over 2 billion dollars on their sport every year. This expenditure covers the costs of equipment, guide fees, transportation, hotel bills, and related items; and much of this money goes into local communities and small industries. The food value of non-commercial fish and game taken annually exceeds a half-billion dollars. The value of the raw fur catch (including fur animals reared in captivity) in 1944 has been estimated at between 75 and 100 million dollars. In 1944 the Bureau of Internal Revenue collected $68,814,902.08 in taxes on furs and fur-trimmed apparel; this tax represented a retail sale of $426,280,792. In the year ending June 30, 1945, proceeds of the sale of state and federal licenses for hunting and fishing totaled $27,567,279, part of which was used to pay the salaries of nearly 8,000 state and federal employees engaged in wildlife work.

From an economic standpoint, therefore, our wildlife and fishery resources must certainly be classified as big business. Their worth becomes the more significant when we realize that perhaps the greatest benefits derived from hunting and fishing are the intangible values in health, happiness, good citizenship, and better living. It would be a serious mistake to underestimate these esthetic and spiritual values, for man does not live by bread alone.

Fish and wildlife must be recognized as major natural resources, to be fostered carefully in any plans for the future. The facts and figures just presented, indicative of the value of these great natural resources, should likewise give convincing proof that adequate development of the Missouri River basin (or any other section of our country) cannot be achieved unless the wildlife and fishery resources are taken into account and given their fair share of consideration.

Missouri River Basin in Relation to Wildlife Production

The Missouri River basin is of primary importance in the management of our fish and wildlife. By way of illustration we might point out that the Missouri River basin, though highly productive of many forms of native wildlife, is by far the most important duck-nesting territory in the United States. As these ducks migrate to other sections of the country, their value has national rather than local significance and their habitat has corresponding importance. It is conservatively estimated that hunters and fishermen expend $422,000,000 annually to pursue their sport in the states wholly or partially within this watershed. A great many people from other sections of the United States come to the Missouri River basin to hunt and fish.

Because of the importance of this section of the country as waterfowl breeding grounds, the Fish and Wildlife Service has made here its greatest investment in wildlife refuges. It is conservatively estimated that these refuges are worth betwen 10 and 15 million dollars. It is probable that they could not be replaced for that today.

Most sections of our country are greatly underpopulated by waterfowl. This condition makes it imperative that every effort be made to increase production on our principal breeding grounds.

In view of the importance of this section as a source of production, the development plans for the Missouri River basin not only must include measures designed to preserve existing resources but also afford every opportunity to increase their abundance. Fish and wildlife are among our major natural resources, and wise development of any area must provide adequate safeguards and assistance for all such assets. Maximum production comes only from proper stewardship. It would seem self-evident, therefore, that maximum multiple-use (as far as it is economically feasible) should be made of all such publicly supported projects.

Conservation and Economic Development of the Missouri River Basin

Conservationists generally and sportsmen in particular, within and without the Missouri River basin, are somewhat apprehensive about what is going to happen to the fish and wildlife resources therein by reason of the program for the development of the Basin's waters for irrigation, flood control, hydroelectric power, and navigation. Too frequently these conservationists and sportsmen have found to their sorrow and disgust that most engineers and far too many officials measure the value of water only in terms of acre-feet or kilowatt hours. A review of river-development projects and impoundments in the past shows that most of them have been planned, constructed, and operated with scarcely a passing thought of their actual or potential wildlife values. With few exceptions, the wildlife values developed were incidental if not almost entirely accidental. It was rare indeed that planning and development for wildlife and engineering progressed concurrently and cooperatively on the same area. When wildlife development occurred on a river basin or impoundment, such development usually came as an after-thought, superimposed on other developments because public sentiment demanded it. Usually, too, this recognition of fish and wildlife interests was granted long after the engineering features had been built, when much development for wildlife and fish was impossible.

If we are to effect the most desirable development of the Missouri River basin, this policy must be abandoned for a broader and more rational view of the totality of our natural resources. The public interest requires that reservoirs be planned to serve multiple purposes, including the development of fish and wildlife resources. To be successful and economical, however, this planned development for wildlife and fish resources must be included in the initial studies for the project and appropriately integrated with all other developments planned for the Missouri River basin. Under the new policy the public will profit by recognition and utilization of such facts as value of the diking off of tributary streams or arms of natural sloughs. These may be diked off economically and quickly before impoundment, though such a task may be prohibitive in cost after impoundment. Likewise, if included in the original plans and built before impoundment, a water-control structure might be constructed economically as part of a bridge or causeway that may partly cut off an arm of a lake; it is improbable that the cost of such a control structure could be justified after impoundment or even after completion of the initial bridge or causeway. It should be expected that not infrequently development for greater fishery or wildlife values will require the expenditure of some additional funds. This expenditure, however, can be a very sound investment that will pay dividends throughout the life of the project.

The development of the Missouri River basin is expected to increase greatly the human population therein. It is imperative, therefore, that in our planning provision be made to maintain existing wildlife and fish resources and to increase these resources wherever possible. Failure to appreciate or anticipate these needs, within the Basin and over the country as a whole, would indicate unwise over-all planning.

PROBLEMS ON MISSOURI RIVER BASIN IMPOUNDMENTS

More than 100 dams have been proposed for the Missouri River basin. These impoundments will effect great changes and necessitate many readjustments. Any impoundment will greatly alter the basic ecology of an area, and the type of plant and animal life occurring in the area will necessarily undergo considerable change. For example, the fish life and food chains of a mountain stream will certainly be eliminated in large measure and replaced by lake fauna and flora after the valley stream becomes a part of a large lake. Such impoundment may eliminate many miles of favored trout stream.

The Fish and Wildlife Service has taken the position that when impoundments destroy valuable wildlife habitat, these areas must be replaced. It is just as important and logical to restore fully a duck or muskrat marsh as it is to move railroads, highways, bridges, or buildings now located in areas to be flooded. The proposed Missouri Valley project will destroy a number of federal refuges and state wildlife areas of major importance and of national significance in the conservation of our wildlife resources. We must insist that these be replaced as nearly as possible with other areas of equal value, including suitable improvement and permanent water supply adequate to meet the needs of wildlife. Also, we insist upon the protection of fishing interests. Necessary initial stocking of fish must be made, and adequate fish screens and ladders provided. Every major pool should maintain a conservation-pool level, below which the water level will not be permitted to drop unless for the benefit of wildlife. During the spawning season every effort should be made to maintain as nearly constant a pool level as possible.

The kind of management or mode of operation of a reservoir will largely determine its effect upon fish and wildlife. Measures for the development of wildlife may include the planting of appropriate aquatic, emergent, and terrestrial food and cover plants; the diking of natural water basins or subimpoundments where appropriate water control for wildlife can be effected; the control of coppice and other undesirable plants that prevent the establishment of desirable food species; sharecropping and otherwise growing food for wildlife; regulation, control, or planting of wildlife species.

Before flooding, all areas to be impounded should be properly cleared. Ditching facilities should be provided so that low areas may drain directly into the main basin, thus minimizing the chance of having fish become stranded during draw-down periods and increasing the chance of survival. Serious consequences to the fisheries will follow any program of irrigation that does not include adequate measures to prevent the destruction of fish in diversion works. Fish screens must be installed to prevent these losses in channels that are only dead-end courses in irrigated lands. Where migratory fish are involved, provision should be made for ladders that will insure free upstream and downstream passage over dams and other obstructions and thus permit the fish to carry on the spawning migrations.

Pollution is a menace to both fish and wildlife resources. The Fish and Wildlife Service has assumed the responsibility of calling attention to sources of pollution on all reservoir projects and of recommending abatement. Further, the Service ordinarily recommends that project plans include the prevention of establishment of sources of pollution in the future.

It is unfortunate that the needs of flood control, irrigation and hydroelectric power development are to a degree in conflict with the needs of fish and wildlife. Normally, stability of water level best serves wildlife and fish interests. Extreme fluctuation of water level is usually very damaging to spawning fish and to wildlife plant foods. Some of the harmful effects of water fluctuation can be cushioned by timing the fluctuation over certain periods of the year. To insure fish in the stream below the dam, a minimum head of water must at all times be flowing from or bypassing the reservoir. Flow of excessive volume and turbulence is harmful.

Sometimes smaller subimpoundments can be made and managed almost exclusively for wildlife and fish. As a rule, smaller areas are more productive than the very large areas.

It will be necessary, in any case, to allocate a limited amount of flowage for fish and game development.

POSSIBILITIES ON MISSOURI RIVER BASIN IMPOUNDMENTS

The Missouri River and many of its tributaries east of the Rocky Mountains are relatively low in fish production. The increased shoreline and water acreage should favor fish production. Moreover, the additional storage reservoirs will certainly reduce floods and silting, so that the quality of the water should be improved greatly, and this in turn should favor fish production. If sections of free-flowing streams occur below impoundments, these sections—because of the desilting action of the dams and the diminished threat of floods—may become better than they were formerly.

Given reasonable consideration, certain impoundments may be expected to benefit wildlife in a number of respects. Undoubtedly, water will be provided where no permanent supply now exists. A number of species of wildlife are fitted by nature to thrive in an agricultural environment. Pheasants, which abound in favored agricultural environment of the Missouri Valley, should become more abundant and widespread where irrigation is practiced. It is probable that on tributary streams and diversion canals will be developed new lakes and smaller ponds, which will favor waterfowl, shorebirds, and many groups of terrestrial species. New marshes, seeps, and wet areas will favor certain species of birds, muskrats, and a great variety of non-game species. Impoundments may obliterate some present refuges, but others may be created specifically for wildlife.

LEGISLATION FOR COORDINATED DEVELOPMENT

Though engineers generally have given little consideration to wildlife values in their impoundments, one great weakness in Federal water-control programs of the past has been that neither the Bureau of Reclamation nor the Army Engineers have had in their acts the basic authority to use funds for the benefit or development of fish and wildlife resources. The Bureau of Reclamation may spend money for irrigation; the Army Engineers are authorized to spend money to aid flood control, develop hydroelectric power, and foster navigation; but under law neither agency has been able to spend money to protect and build up the fish and wildlife resources potentially or actually inherent in the water and engineering structures being built.

To correct this deficiency in law and the consequent lack of proper coordination among government agencies and between these engineering agencies and the state fish and game departments, the Revised Coordination Act (H.R. 6097) was passed and became Public Law No. 732 (79th Congress) on August 14, 1946. The Coordination Act of March 10, 1934 (48 Stat. 401—16 U.S.C. 661–666), had been a step in the right direction, but it lacked authority. That legislation merely provided that the Bureau of Fisheries and the Bureau of Biological Survey (consolidated as the Fish and Wildlife Service in 1940) "may consult with the Bureau of Reclamation or other governmental agency controlling the impounded waters, with a view to securing a greater biological use of the waters. . . ."

The 1946 legislation provides that no agency of the Federal Government may construct any dam or other water facilities without first having the plans and programs studied by the Fish and Wildlife Service and the State fish and game commissions. Though it grants no veto power to the wildlife agencies, this law does provide that fish and wildlife resources shall be planned along with other interests and reported to Congress along with the plans for the proposed dam construction. If there then be conflicts, the Congress presumably will resolve them. The act further provides that, "In accordance with general plans covering the use of such waters and other interests for these purposes, approved jointly by the head of the department or agency exercising primary administration thereof, the Secretary of the Interior, and the head of the agency exercising administration over the wildlife resources of the State wherein the waters and areas lie, such waters and other interests shall be made available without cost for administration (a) by such State agency, if the management thereof for the conservation of wildlife relates to other than migratory birds; (b) by the Secretary of the Interior, if the waters and other interests have particular value in carrying out the national migratory bird management program."

It should be understood clearly that the Fish and Wildlife Service is not interested in unlimited expansion of areas to manage—and especially to maintain as inviolate sanctuaries. Perhaps a few of the larger or more strategically located units would best serve the nation if they were fitted into the refuge program, but better than 90 percent of the newly developed wildlife areas in river basins should go to the States for management. As a national agency, however, the Fish and Wildlife Service is perhaps in a position to work more effectively with the Bureau of Reclamation and the Army Engineers than could the 48 states working alone as individual states. It is obvious that the greatest success will result from a well organized, well directed, cooperative approach made simultaneously by all agencies and interests in the field of conservation.

Another important feature of Public Law No. 732 is that it gives the construction agency basic authority to spend funds to develop or improve fish and wildlife values. This provision should prevent the construction agency from leasing lands of primary wildlife value to private shooting clubs, as has been done in the past. The new law places the authority and responsibility for the planning and development of the wildlife and fishery resources with the state and federal agencies set up to handle this work.

Unquestionably, Public Law No. 732 is one of the most important and far-reaching wildlife measures ever enacted. Many of the State Conservation Commissioners, the Izaak Walton League, and other public and private agencies and individuals gave detailed support to Congressman Willis Robertson of Virginia, who sponsored the measure and introduced it into the House. The States and other public and private agencies and individuals along with Mr. Robertson deserve much credit for having this Bill enacted into law.

Though there are—and there always will be—problems, it must be said that the degree of cooperation and coordination among federal and state agencies is very much better now than formerly. In this connection it might be noted that during the past year this Service has had access to engineering plans of the Bureau of Reclamation and of the Army Engineers.

While the amended Coordination Act (Public Law No. 732) is an exceedingly important and far-reaching piece of legislation, in my opinion, it does not yet go far enough. More is needed in the line of maintenance and management. Provision should be made to prevent a type of administration and management of a completed reservoir that will unnecessarily damage the fishery or wildlife resources of that impoundment. Adjustments after completion of the reservoir to improve further the area's natural resources should be made whenever possible and economically feasible.

It seems to me this Act might further be amended to provide that the maximum multiple public interest be served when other important structures besides impoundment are erected by or for Federal agencies. The construction of jetties, sea walls, or piers designed to control beach erosion or aid navigation is important as recreational facilities. This applies particularly to the Eastern seaboard where public-owned beaches are almost non-existent. A notable example is New Jersey where the private individuals who own the coast line are requesting Federal aid in combatting beach erosion. Any structure of this type to be erected through Federal assistance should be planned to allow salt-water angling, and after completion it should remain as public property open to public utilization. Several hundred thousand people seek their recreation along the Atlantic seaboard annually, and consideration must be given to perpetuating the opportunity of salt-water angling. This can be done with little variation in design and with very little or no extra cost.

PARTICIPATION OF THE FISH AND WILDLIFE SERVICE

There is scarcely a river system in the country that engineers have not considered "developing" with a series of dams and power plants, diverting for irrigation, or deepening for better and bigger navigation. Some of these projects are unquestionably in the public interest; others would probably result in serious loss of natural resources that are worth more than the benefits to be derived from power, navigation, flood control, or irrigation. Requiring a decision on each project or group of projects, the Fish and Wildlife Service bases its evaluation upon a thorough investigation of the site and of the plans for construction and operation. Some 450 proposed projects are now awaiting study by our biologists.

To coordinate river-development programs more effectively and to insure better consideration for wildlife and fishery resources, the Fish and Wildlife Service has established an Office of River Basin Studies. This office maintains a staff of wildlife and fishery biologists to examine the plans, study on the ground the present and potential values for wildlife and fishery resources, and appraise the probable gains and losses through the proposed projects. This work is done in close collaboration with the states. The reports developed, though not jointly written, are prepared in collaboration with the state fish and game departments concerned.

In order to reach sound decisions regarding the net effects of a project on fish and wildlife, this Service prepares an estimate of the value of present resources and of those which may appear if the project is put into operation. Estimates of values are not reported in general or comparative terms, but to the greatest extent possible they are given directly in terms of monetary value.

Conclusions

The fish and wildlife resources of this country have definite economic value as well as esthetic and spiritual appeal. The Missouri River basin provides fish and wildlife habitat that has national as well as local significance. The economic development of the Missouri River basin should be based upon plans incorporating sound biological principles and measures designed to preserve and increase these major natural resources. Recent legislation will permit conservation interests to introduce into the original plans such desirable modifications in structures and their operation. The Fish and Wildlife Service, in cooperation with other Government agencies and the states concerned, is studying proposed projects for their comparative values and effect upon these resources.

DR. VAN OOSTEN: I think we can agree that this symposium is one of the finest discussions we have ever had in either of the two societies. We must all have a better understanding now of the program of the Missouri Valley project, and on behalf of the two societies I wish to thank General Pick, Mr. Sloan, and Dr. Cottam for coming here to discuss the various phases of the project.

MR. HOFFMASTER: Thank you, Dr. Cottam, for participating in this discussion. I think you will all agree that the door is open for a real job of coordination in the development of the enormous resources of the Missouri River basin. It has been said here that if we sit idly by and allow errors to creep in, it is our own fault. We had better take that statement seriously. It is not the responsibility of the federal agencies alone to take the initiative in the integration and coordination of these resources; so let us accept that invitation as a challenge and see what we can do about it.

Part III

Business Sessions

AMERICAN FISHERIES SOCIETY

SEVENTY-SIXTH ANNUAL MEETING

The seventy-sixth annual meeting of the Society was opened in the Continental Room, St. Paul Hotel, St. Paul, Minnesota, at 9:45 a.m., Wednesday, September 11, 1946, with President John Van Oosten in the Chair. The agenda were as follows:

Wednesday, September 11

Morning: Symposium on the Missouri River Basin (joint meeting with the International Association of Game, Fish and Conservation Commissioners); appointment of sessional committees.

Afternoon: Open for committee meetings and conferences.

Evening: Annual banquet—St. Paul Auditorium.

Thursday, September 12

Morning: Reports of officers, standing committees, and special committees.

Afternoon: Presentation and discussion of papers.

Friday, September 13

Morning: Presentation and discussion of papers.

Afternooon: Presentation and discussion of papers; reports of sessional committees; election of officers and installation of the new President; concluding business.

Saturday, September 14 to Monday, September 16
Bus tour of northern Minnesota, under the sponsorship of the Minnesota State Tourist Bureau.

OPENING REMARKS OF THE PRESIDENT

John Van Oosten

When I was a child there prevailed among our elders a general maxim that "children should be seen and not heard." Apparently this same policy exists more or less tacitly with respect to the Presidents of the American Fisheries Society. In examining the opening remarks of many of our past presidents I observed that nearly all of them were very brief. Even though I may have shattered recent precedent with respect to the length of term in office (only one man was president longer than I have been; he served a term of 8 years, from 1874 to 1882, and by some strange coincidence his name was Roosevelt!)—I do not intend to change the custom with respect to presidential speeches. My remarks therefore will be brief.

A long review of the events that have taken place between our last meeting in St. Louis, Missouri, in 1941, and this conference of 1946 is not required, since at the end of each year during this interval I prepared a brief résumé of the principal facts that formed the bases of actions taken and decisions made by the Executive Committee. These summary remarks appeared or will appear in the several Transactions, and the Society will then have for future reference a permanent record of the background of these various decisions.

I am extremely happy to be able to open the Seventy-sixth Annual Meeting of the American Fisheries Society, following the forced cancellation, as a result of World War II, of the seventy-second, seventy-third, seventy-fourth, and seventy-fifth meetings. Many of our members have contributed directly and indirectly to the successful termination of this catastrophic world conflict. In a sense it may be said that the battle was won by our superior supplies, raw materials, and natural resources of which the fisheries constituted an important part. I am happy to report that in spite of the many handicaps that confronted the fishing industry in the United States and Canada as the result of shortages in manpower, vessels, equipment, and supplies, it was nevertheless able to maintain a nearly normal production during the war years. In the United States the industry obtained invaluable assistance from the Office of the Coordinator of Fisheries set up in the Department of the Interior under the jurisdiction of members of the Fish and Wildlife Service. In Canada, similar assistance was provided through the various divisions of the Department of Fisheries at Ottawa.

I believe it is safe to say that in World War II our authorities adhered to a much saner conservation policy than they did in World War I. In spite of the urgent need for fish and fishery products during the recent conflict, every effort was made by those in authority to prevent over-exploitation. Attempts to plunder our biological resources under the guise of aiding the war effort generally met with failure. Partly as a result of this wise policy we are now able to resume, on the whole, the normal production that was maintained before the war, and to fulfill rather satisfactorily the existing demands upon our fishery resources, both commercial and non-commercial.

With the return of our veterans, many of whom have acquired a fondness for the out-of-doors, there will undoubtedly develop an increased interest in and demand for fishing, a demand which will carry with it greater responsibilities on the part of those of us to whom has been entrusted the welfare of our biological resources.

In this year's program we have departed somewhat from our usual custom of the recent past. We have returned to a 3-day scheduled meeting. For the first time in the Society's history, I believe, we are holding a joint meeting with the International Association of Game, Fish and Conservation Commissioners. Not since 1937 has the American Fisheries Society held a 3-day meeting. I trust that both innovations this year will prove beneficial to the two organizations. Many of us belong to both societies; we have a common interest in the fisheries and certain related wildlife problems; we hold our meetings during the same week and in the same place, and share the entertainment. Perhaps it might be well for us to adopt the policy of holding a joint meeting as we are doing this year, and thus bring the two societies into even closer contact.

APPOINTMENT OF SESSIONAL COMMITTEES

Time and Place

Seth Gordon, Pennsylvania, *Chairman*
I. T. Bode, Missouri
H. H. MacKay, Ontario
J. N. Gowanloch, Louisiana
O. L. Meehean, Illinois

Resolutions

Ralph Hile, Michigan, *Chairman*
Kenneth Reid, Illinois
C. N. Feast, Colorado
C. R. Gutermuth, D. C.
H. H. MacKay, Ontario

Nominations

F. A. Westerman, Michigan, *Chairman*
W. C. Senning, New York
Paul Needham, Oregon
A. D. Aldrich, Oklahoma
E. Higgins, D.C.

Auditing

J. R. Simon, Wyoming, *Chairman*
C. F. Culler, Minnesota
R. W. Eschmeyer, Tennessee

REPORTS OF OFFICERS

REPORT OF SECRETARY-TREASURER

RUSSELL P. HUNTER

The Secretary-Treasurer's Report is presented under three headings: (1) Treasurer's Report; (2) Membership Statistics; and (3) Meeting of the Executive Committee, March 12, 1946. The three reports follow in order:

TREASURER'S REPORT

July 1, 1945—June 30, 1946

GENERAL FUND

RECEIPTS

Balance on hand, July 1, 1945		$ 4,022.85
Annual Dues		
Individuals		
For the year 1939-1940	$ 3.00	
1940-1941	3.00	
1941-1942	3.00	
1942-1943	15.00	
1943-1944	36.00	
1944-1945	111.00	
1945-1946	624.00	
1946-1947	39.00	834.00
Libraries		
For the year 1945-1946	$ 6.00	
1946-1947	2.00	
1947-1948	2.00	
1948-1949	2.00	
1949-1950	1.00	13.00
Clubs and Dealers		
For the year 1943-1944	5.00	
1944-1945	10.00	
1945-1946	95.00	
1946-1947	5.00	115.00

State Membership		
For the year 1943-1944	20.00	
1944-1945	60.00	
1945-1946	560.00	640.00
Life Membership		50.00
Sale of Transactions		449.77
Sale of Index		15.47
Sale of Reprints		11.25
Checks collected and credited to account		26.02
Total Receipts		$ 6,188.06

DISBURSEMENTS

Refund on Transactions		$ 10.00
Postage		94.27
Premium on fidelity bond		18.75
Premium on insurance		13.50
Rental of safe deposit box		4.80
Audit of accounts		75.00
Clerical services		
R. P. Hunter		100.00
K. M. Kane		382.95
Travel expenses (N. Y. meeting)		20.00
Withholding tax (Salary of K. M. Kane)		17.01
Checks charged to account until collected		30.00
Printing		75.95
Supplies		13.34
Petty Cash		5.00
Activity charge at bank		3.88
Total disbursements		$ 864.45
Total Receipts, General Fund	$6,188.06	
Total Disbursements	864.45	
Balance on hand June 30, 1946	$5,323.61	

PERMANENT FUND

Balance on hand July 1, 1945	$ 3,271.41
Interest on Savings Account Mortgage Certificates	209.01
Dividends on Commonwealth & Southern Preferred Stock	45.00
On hand June 30, 1946	$ 3,525.42

General Fund	$5,323.61
Permanent Fund	3,525.42
Investments	5,871.85

MEMBERSHIP STATISTICS

On the membership roll as of September 5, 1946, there are 428 active members with their dues paid through June 30, 1946, and 114 members in arrears carried during the war period. In explanation of the latter item it should be stated that on the advice of the Executive Committee the normal policy of dropping members for non-payment of dues at the end of each year was not followed. In the next volume of the TRANSACTIONS, membership lists will be printed and the names of members who have not paid their dues or who have dropped out of sight due to war activities will be starred. The reason for that is of course that the Society wishes to pick these members up again. It would be much appreciated if the members themselves or their friends and acquaintances would notify the Secretary-Treasurer of the proper addresses, because on account of war activities it has been impossible to follow them up.

Club memberships total 21; life members, 43; libraries, 47; and honorary members, 7.

With respect to state memberships, a list of non-member states is presented in the hope that all the states may be brought into membership:

Arizona
California
Colorado
Delaware
Florida
Georgia
Kansas
Kentucky
Mississippi
Montana
Nevada
New York
North Dakota
Ohio
Pennsylvania
Rhode Island
South Carolina
South Dakota
Utah

The other states not included in that list are on the membership roll; naturally the Society desires 100-percent representation of state memberships.

Regarding the status of the TRANSACTIONS, the favorable balance reported as at the present time, in the neighborhood of $6,000 carried in our cash account, gives a rosier picture of our financial position than is actually true. It must be remembered that Volume 73 has just come off the press, and the printing bill of $2,200 for that volume still remains to be paid. Volume 74 is in press and Volume 75 will be printed as soon as possible. A new volume, No. 76, will be the result of this meeting. The Society is faced then with the responsibility of publishing five volumes in the next 2 years, or six in the next 3 years, in order to catch up. If printing costs stay at their present level, and no immediate decline is anticipated, at least $2,000 will have to be made available for each of these proposed volumes. The Society must give consideration to an increase in its annual dues in order to bring up its income to a point which will insure its solvency 3 years hence. It is recommended that a committee be appointed to give thought to this matter for the coming year and to report at the next meeting.

Mention should be made of the resignation last year of Miss Ethel M. Quee, who, for a number of years, served as Assistant Secretary of this Society. She was followed by Mrs. H. J. Deason, who served for a short time, and finally Miss Katherine Kane has been appointed to fill that position. I want to express the gratitude of the Society for the valuable service rendered by Miss Quee during the time she was Assistant Secretary.

Aid of the membership is sought in getting new members for the Society and in urging the rejoining of members who have been on the rolls in the past. Captain C. F. Culler has demonstrated what can be done in the way of bringing in new memberships. Just prior to this meeting he sent in 20 applications for membership from men interested in fish culture in this area. The Society could well recognize the signal service that has been rendered by Captain Culler and give him a vote of thanks for this fine job.

Meeting of the Executive Committee

On March 12, 1946, a meeting of the Executive Committee was held in the Hotel Pennsylvania, New York City. Committee members present were: President John Van Oosten, First Vice-President Joe Hogan, Past-President James Brown, and Librarian Kenneth E. Cobb. Other members of the Society in attendance were: A. D. Aldrich, Theodore C. Fearnow, John R. Gudey, Nelson Marshall, Edward C. Raney, Lloyd L. Smith, Jr., Paul E. Swazy, Lyle M. Thorpe, Dwight A. Webster, and Fred A. Westerman.

The agenda for discussion at this meeting comprised formulation of plans for our present joint meeting with the International Association of Fish, Game and Conservation Commissioners. Also considered by the committee was a recommendation that any new members joining the society should be supplied a copy of Volume 73 of the Transactions as soon as it becomes available, and advised that they may expect to receive subsequent volumes as issued at a cost of three dollars each. The Secretary-Treasurer requested from the committee authorization to have an audit made of the Society's books for the years 1943, 1944 and 1945, when no meetings were held. The request was granted, and the auditors' report referred to members of the Executive Committee prior to its submission to the Auditing Committee appointed by the President at this meeting.

REPORT OF THE DIVISION OF FISH CULTURE

James R. Simon

To one who has been removed from the scene for a time, it is evident that yesterday's barely discernible trends in fish management are today's generally established policy. Most responsible agencies in the administration of fisheries are practicing some sort of management, however small, instead of depending solely on the stocking of fish. This trend is most noticeable in the field of warm-water fish culture. Instead of a widespread opinion that stocking lakes and streams is the only means of maintaining fishing, it is generally conceded that stocking is but one very important management method. As never before, management agents and the hatchery man are working together, and it is indeed gratifying to note that there is cooperation rather than antagonism between "hatchery people" and "management people."

A perusal of the official publications of federal agencies and state departments leads one to believe that "the proper use of large fish in stocking managed waters" is the aim of most responsible administrative agencies even though in most instances the primary objective is to rear as many legal-sized fish as budgets allow. This bright prospect is one which might possibly be dimmed by the fact that there is evident among the fishing public the attitude that unlimited numbers of legal-sized fish can be supplied and, alarmingly, agreement by those who rear the fish, despite their use of other management practices. A halt must be called somewhere along the line, simply because there is a limit to the supply of all forms of wildlife, whether artificially or naturally propagated, if fishing and hunting are to remain sports and not become huge glorified commercial ventures. We do not want to encourage generations of fishermen whose urge to go fishing is induced by the passing of the hatchery truck, nor can we displace all our wild stock for the sake of bowing to the pressure that insists upon the planting of hand-reared fish. In any event we are committed to a dual program of rearing enormous numbers of adult fish and a minimum of fry and fingerlings for special use while sponsoring an accelerated program of investigation and management practice.

Management is being given a fair trial. Publications of the various departments are full of such terms as 'midseason stocking," "creel census," "stream improvement," "watershed improvement," . . . That part of this activity is still in the publicity stage does not detract from its value. The very fact that the various agencies will even take it upon themselves to discuss management practices in fish culture is most heartening. The fishing public of America is actually on the verge of believing that fish culture and management together can do the job. Year-around fishing in farm ponds and larger bodies of water, particularly for the panfishes, is being tried, cautiously by some and almost without restraint by others. Such practices, because they are likely to be carefully observed and reported, will be of critical value to fishery administrators.

Despite material shortages, plans for bigger and better trout hatcheries are being made in all parts of the nation. Trout culturists are searching for springs of greater volume with higher water temperatures, for the purpose of producing larger numbers of fish in less time. Because of acute necessity, new foods for trout are being tried and new food sources are being sought.

Perhaps the greatest need in the field of fish culture today is an adequate formal training program for hatchery men and support of such a program by the hiring agencies. Before a program of training can be initiated, it will be necessary for colleges to schedule accredited courses. Only one college in a whole region needs to offer fish-culture training. In the nation today, there are extremely few institutions of higher learning which have set up any sort of curriculum in fish culture, although there are sufficient wildlife departments in the various colleges. Not so many years ago the aquatic biologists in fishery work were the only trained men in the field and they were few; then the fish-culturist, a relatively untrained man, had the field almost to himself. After an apprenticeship of a few months or a few years in a regularly established station he was considered the authority in the field of artificial propagation of game fishes and despite his lack of formal training and the need to learn the hard way, he did a commendable job. At least he reared the fish, which was his only duty. He was not responsible in most instances for what happened to them later. Between the trained field biologist and the fish-culturist there remains a large gap which can be filled at least in part by training of the fish-culturist.

The training of the hatchery man has not kept pace with the training of others in this general field of work. Why not add to the value of the service these men are capable of giving? Today many hatchery apprentices are returned veterans who have special privileges in formal training. Since any agency profits by the use of trained men, it seems logical that the hiring agency should urge the training of its own employees by the simple expedient of making up the difference in pay—the difference between that allowed on the G.I. Bill of Rights and that which the man is receiving.

The President called successively for the report of the Librarian, Kenneth E. Cobb, and of the following Divisional Vice-Presidents:

Aquatic Biology and Physics	R. W. Eschmeyer
Commercial Fishing	W. K. Schofield
Protection and Legislation	W. C. Adams
Angling	C. D. Shoemaker

None of these officers of the Society had made a report available for presentation. The President commented regretfully on this wholesale defection.

PRESENTATION BY MR. SETH GORDON OF PHOTOGRAPH OF MEMBERS IN ATTENDANCE AT 1915 MEETING OF THE SOCIETY

I am in a sense an interloper here, since I am not actually engaged in fishery administration. Some of you may have wondered why I am so actively interested in the American Fisheries Society. Actually I have followed its activities ever since the meeting in Allentown, Pennsylvania, in 1921, when I was just a young fellow getting acquainted with this work. When I got into the national field with the Izaak Walton League and later with the American Game Association I recognized more and more the importance of this fine old organization.

One of the things I regret is that not all the states regularly maintain their memberships in the Society, and the further fact that not all the administrators stay for these meetings. Your Commissioners in many cases are the men who ought to hear these discussions in detail so that they will better comprehend some of the problems that are being presented. Too often items of information come out of these sessions which you have to carry back second-hand; or you wait until they are printed and then hope your administrators will read them and that the next time the Society meets you will get permission to attend; but the administrators often are not cognizant of what has taken place.

One thing which has impressed me in this organization is the fact that the men who are associated with it are sufficiently interested in and satisfied with their vocation in life to encourage their sons and even their daughters to take up the work and stay with it. It is amazing how many fathers give their children the impression that their job is the toughest in the world and advise them to stay away from it. In fishery work that is not so, and in game work such an attitude is not as frequently met with as it was some years ago, because you men by and large have entered a vocation in which you have continuity of service. One reason is that every Tom, Dick, and Harry does not know your job—although every Tom, Dick, and Harry knows how to run the job of the departmental head! To me it is a wholesome thing, and I am only saying this to encourage the younger men to keep on doing what some of their fathers have done. It is an important work and is becoming increasingly so.

There is another thing I wish we would do more often. When you come to a community where there is an old-time fish-culturist who has rendered great service to the cause, make it a point to see him and make him feel you haven't forgotten about him. It pays bigger dividends than anything else you could do in the half-hour you spend with him.

The other day I stopped off to see the widow of Dr. Henry Baldwin Ward, who died last year. She has been an invalid for some time. While

I was visiting Mrs. Ward, her daughter told me about having gone through Dr. Ward's vast accumulation of scientific material, and she turned over to me for delivery to the Society a very interesting picture of 31 members of the organization taken at San Francisco in 1915. When I looked at it I was astonished to see how few of the persons in it I knew. George W. Field was then President. Among the others pictured are such men as: Dr. Ward, who was then a young man; the former United States Commissioner of Fisheries, Henry O'Malley; David Madsen of Utah; Eben Cobb; and many more whose faces I recognize but whose names I do not remember. Captain Culler and some of the rest of the group here might know some of them. I often think it would be a good idea to publish in the TRANSACTIONS pictures of the officers so that as time goes on one could look back and recall old friends and workers. It might be worth while as a historical record.

Coming back to what I said a moment ago—in the room there are a number of sons of fishery workers. As I looked at that picture I thought of a meeting I attended in Denver and of how few of the old-timers are with us today. How many men in this room attended the Denver meeting in 1925? (No response.) It doesn't seem possible. At that meeting I remember especially one man who was actively interested in fish culture. I refer to Horace Frantz, who took us down to his hatchery and showed us how he was feeding beans to his trout. A lot of folks laughed about it, but he continued to do it. Later a few of us—John Titcomb, Charlie Hayford, and others—went down to visit Horace Frantz, and in this room today I am glad to see one of the boys I have been talking about, a son of Horace Frantz. When I was there in 1925 he was a little fellow; now he is grown up and in the business . Then, of course, there is Eugene Surber, from Minnesota. Everybody knows the work Thaddeus Surber did; he is still living here in St. Paul, and I am sorry he is not at the meeting this morning. Everybody knows Paul Needham; and if Charlie Hayford's son is not in the room, he ought to be.

These sons of men who have been engaged in the fish-culture business are better equipped and better trained than their fathers were, and for that reason are doing better work.

You have an organization which has a big job to do. You can be proud of the traditions of the American Fisheries Society, and you do not need to hesitate to sell it to anybody. Do not hesitate to encourage all of those with whom you are associated in fishery work to join and support the Society. Many back home may be critical of the work you are doing. Why? Largely because they do not understand it. If they could be persuaded to become members of the Society, take an active interest in its work, and read the papers that are published in the TRANSACTIONS, much of the criticism would vanish. It would be a simple matter to lend some of these critics copies of the TRANSACTIONS. Lend them your copy—and hope you will get it back. Point out to them the papers they ought to read and digest, and they will change their attitude because they will appreciate the complicated problems with which you are working.

I will leave the 1915 photograph of the Society with you for your archives. I think it is well that attention should be called to the traditions of this organization, its background and the guild spirit, if you will, that has always prevailed among fishery workers. I hope it will continue.

MR. DENMEAD: I have a picture of members of the Society taken in Louisville, Kentucky, in 1919. It is a very interesting picture, and if the Society wants it I will see that they get it. We should keep these pictures in our library or archives.

THE PRESIDENT: We shall be happy to have it, and to have any others that are available. We might be able some time to publish a picture in our TRANSACTIONS.

REPORTS OF STANDING COMMITTEES

COMMITTEE ON INTERNATIONAL RELATIONS

William C. Herrington [1]

During the 5 years that have elapsed since the American Fisheries Society met at St. Louis, Missouri, on August 25 and 26, 1941, our World has changed in many ways. Probably many of these changes are transitory and will disappear largely when the effects of wartime shortages and economic distortions are overcome. However, we hope that the effects of international cooperation, particularly among the nations of the Western Hemisphere, are here to stay. Necessity has made us appreciate more than ever before, our dependence on the natural resources of the Americas when the going becomes difficult. It has also impressed upon us the tremendously accelerated progress that can be achieved in the solution of complex problems, by the well-coordinated attack of all interested agencies. Only the future can determine how much we will benefit from these lessons.

In the following summary of developments in the field of International Relations, the Committee is indebted greatly to Dr. Hilary J. Deason, who, from his vantage place in Washington, has prepared for the Committee a résumé of international activities since the last meeting of the American Fisheries Society.

U. S. Policy of Conservation of High Seas Fisheries.—On September 28, 1945, the President of the United States issued a proclamation providing for the establishment of conservation zones for the protection of fisheries in certain areas of the high seas contiguous to the United States. The action of the President in regard to conserving the high seas fisheries in which the United States has interest, was taken on recommendation of the Secretary of State and the Secretary of the Interior. This action in establishing a policy for protecting the high seas fisheries is a most progressive step in the field of international policy, for it has provided the means of preserving those resources which are essential for the welfare and existence of our people. The text of the proclamation is as follows:

PROCLAMATION 2668
Sept. 28, 1945
POLICY OF THE UNITED STATES WITH RESPECT TO COASTAL FISHERIES IN CERTAIN AREAS OF THE HIGH SEAS
BY THE PRESIDENT OF THE UNITED STATES OF AMERICA
A PROCLAMATION

WHEREAS for some years the Government of the United States of America has viewed with concern the inadequacy of present arrangements for the protection and perpetuation of the fishery resources contiguous to its coasts, and in view of the potentially disturbing effect of this situation, has carefully studied the possibility of improving the jurisdictional basis for conservation measures and international cooperation in this field; and

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[1] In Mr. Herrington's absence, his report was presented by Mr. F. A. Westerman, a member of the Committee.

WHEREAS such fishery resources have a special importance to coastal communities as a source of livelihood and to the nation as a food and industrial resource; and

WHEREAS the progressive development of new methods and techniques contributes to intensified fishing over wide sea areas and in certain cases seriously threatens fisheries with depletion; and

WHEREAS there is an urgent need to protect coastal fishery resources from destructive exploitation, having due regard to conditions peculiar to each region and situation and to the special rights and equities of the coastal State and of any other State which may have established a legitimate interest therein:

NOW, THEREFORE, I, HARRY S. TRUMAN, President of the United States of America, do hereby proclaim the following policy of the United States of America with respect to coastal fisheries in certain areas of the high seas:

In view of the pressing need for conservation and protection of fishery resources, the Government of the United States regards it as proper to establish conservation zones in those areas of the high seas contiguous to the coasts of the United States wherein fishing activities have been or in the future may be developed and maintained on a substantial scale. Where such activities have been or shall hereafter be developed and maintained by its nationals alone, the United States regards it as proper to establish explicitly bounded conservation zones in which fishing activities shall be subject to the regulation and control of the United States. Where such activities have been or shall hereafter be legitimately developed and maintained jointly by nationals of the United States and nationals of other States, explicitly bounded conservation zones may be established under agreements between the United States and such other States; and all fishing activities in such zones shall be subject to regulation and control as provided in such agreements. The right of any State to establish conservation zones off its shores in accordance with the above principles is conceded, provided that corresponding recognition is given to any fishing interests of nationals of the United States which may exist in such areas. The character as high seas of the areas in which such conservation zones are established and the right to their free and unimpeded navigation are in no way thus affected.

IN WITNESS WHEREOF, I have hereunto set my hand and caused the seal of the United States of America to be affixed.

DONE at the City of Washington this twenty-eighth day of September, in the year of our Lord nineteen hundred and forty-five, and of the Independence of the United States of America the one hundred and seventieth.

(SEAL) HARRY S. TRUMAN

By the President:
DEAN ACHESON
Acting Secretary of State.

EXECUTIVE ORDER 9634

PROVIDING FOR THE ESTABLISHMENT OF FISHERY CONSERVATION ZONES

By virtue of and pursuant to the authority vested in me as President of the United States, it is hereby ordered that the Secretary of State and the Secretary of the Interior shall from time to time jointly recommend the establishment by Executive orders of fishery conservation zones in areas of the high seas contiguous to the coasts of the United States, pursuant to the proclamation entitled "Policy of the United States with Respect to Coastal Fisheries in Certain Areas of the High Seas," this day signed by me, and said Secretaries shall in each case recommend provisions to be incorporated in such orders relating to the administration, regulation and control of the fishery resources of and fishing activities in such zones, pursuant to authority of law heretofore or hereafter provided.

HARRY S. TRUMAN

THE WHITE HOUSE
September 28, 1945

Mexican Policy Proclamation.—On October 29, 1945, the Mexican Government issued a proclamation which is somewhat similar to the proclamation of the United States with respect to the establishment of conservation zones mentioned above. It, however, combined the provisions of this proclamation with a proclamation relating to mineral resources and petroleum resources on the Continental Shelf issued by President Truman on September 28, 1945, simultaneously with the fishery proclamation. The Mexican proclamation provides for jurisdiction and ownership over resources adjacent to the Mexican coast up to the 200-meter contour. The Mexican proclamation also states the intention of the Mexican Government to recognize legitimately developed fishery activities by citizens of other nations off its coasts within are areas referred to above.

Pacific Fur Seals.—Notwithstanding the benefits derived by all parties (United States of America, Canada, Japan, and Russia) to the Fur Seal Convention of 1911, the Japanese Government gave notice of abrogation on October 23, 1940, and in accordance with its provisions the Convention terminated on October 23, 1941. It was then determined through conversations between appropriate officials of the United States of America and Canada, that a temporary agreement should be made for the purpose of protecting the rights and interests of the two governments in the fur seal herds of the Pribilof Islands. Accordingly, a provisional agreement was concluded by an exchange of notes between The Secretary of State and the Canadian Minister in Washington (December 8 and December 19, 1942) which incorporated, in general, the provisions of the Fur Seal Convention of July 7, 1911. The outstanding provisions are the continued ban on pelagic sealing and the taking of seals at sea, and the division of the former Japanese share of the proceeds of the seals taken annually on the Pribilof Islands. Under the 1911 Convention Japan received 15 percent of the take and Canada 15 percent of the take. Under the provisional agreement, the United States retained two-thirds of the former Japanese share and Canada received one-third, making Canada's total percentage share 20 percent instead of 15 percent as formerly. The Congress of the United States early in 1942 enacted implementing legislation to give effect to the provisional agreement. It is expected that the new

Fur Seal Treaty will be negotiated as soon as the necessary conversations can be undertaken.

International Fisheries Commission (Halibut).—The International Fisheries Commission ,established in 1924 by Convention between the United States and Canada for the study and later the regulation of the Pacific halibut fishery, continues to provide an example of the practical value of international cooperation and the application of sound conservation principles. The regulations formulated by the Commission on the basis of an extensive and thorough study of the fishery not only arrested the steady decline in the yield of the fishery, but have resulted in a very considerable increase in the catch above the 46,500,000 pounds produced in 1935.

International Pacific Salmon Fisheries Commission.—The International Pacific Salmon Fisheries Commission was established by means of a Convention between Canada and the United States for the protection, preservation, and extension of the sockeye salmon fishery in the Fraser River System, which was signed at Washington on May 26, 1930. The sockeye salmon was once so abundant that in 1913 it produced a pack of almost a quarter of a billion 1-pound cans which at present prices would be worth over $40,000,000. Now, one-eighth of that quantity is considered a good pack. The blasting of rocks during railroad construction in the narrow gorge of the Fraser River is charged with causing this huge decline by obstructing passage of the fish to the upriver spawning grounds. Subsequent investigations disclose that great numbers of fish, even before the occurrence of the obstruction, were retarded by the narrow gorge in the canyon and could not reach their spawning grounds. After intensive investigation it was shown conclusively that the terrific rush and surge of the water at Hell's Gate Canyon is largely responsible for failure of the salmon run to recover its former magnitude. On the basis of this investigation the Commission recommended the construction of so-called fish ladders to eliminate the difficulty, and the Commission also recommended the removal of some other obstructions. By means of an exchange of notes during 1944, the governments of Canada and the United States agreed to share equally the cost of the construction of the fishways and other remedial work at an aggregate cost of $2,000,000. That construction work is now in progress.

Under the terms of the Convention, no regulation of the salmon resources should be undertaken until after the passage of two full life cycles of the salmon. Regulation of the sockeye salmon fishery under the Convention became possible for the first time during 1946. Because of the difficulties in drafting and effecting the passage of the necessary implementing legislation, by temporary expedient, arrangements were made for the promulgation of necessary regulations by the State of Washington and by the Province of British Columbia, to protect the sockeye salmon fishery of the Fraser River, which was done during the spring of 1946. It is believed that implementing legislation to give full effect to the provisions of the Convention, and to include regulatory features, will be presented for the consideration of the 80th Congress which will convene in January 1947.

International Whaling Conference.—An International Whaling Conference convened in London on November 20, 1945, and was concluded on November 26, with the signature of the final act of the Conference and a Protocol. The Countries represented by official delegates were as follows: Union of South Africa, Australia, Canada, Denmark, France, Netherlands, New Zealand, Norway, United Kingdom of Great Britain and Northern Ireland, and the United States of America. Mexico and Newfoundland were represented by observers. A total of 45 delegates, observers, and technical advisors attended the meetings of the Conference. The American delegates were Dr. Remington Kellogg of the Smithsonian Institution, and Dr. Ira N. Gabrielson, Director of the Fish and Wildlife Service. The technical advisors to the United States delegates were Donald E. Kennedy, Wm. E. S. Flory, Charles I. Bevans of the Department of State, John M. Allison of the American Embassy, London, Dr. H. J. Deason, Fish and Wildlife Service, and Commander James D. Kraik, United States Coast Guard. By reason of the urgent and critical fats and oils situation the Conference dealt largely with emergency measures for the 1945-46 and 1946-47 Antarctic whaling season. A maximum catch limit of 16,000 blue whale units was set. At this conference, the United States delegation announced the intention of the United States Government to call a whaling conference in Washington late during 1946 in order to consider long-range programs and policies with regard to whaling.

International Board of Inquiry for the Great Lakes Fisheries.—This International Board of Inquiry was established February 29, 1940, through an exchange of notes between the Governments of the United States of America and of Canada for the purpose of studying methods of preserving and developing the Great Lakes fishing industry. The establishment of the Board was recommended by a conference of public officials held in Detroit, Michigan, on February 25 and 26, 1938, and at subsequent conferences held in Chicago, November 21 and 22, 1938, and December 5, 1938. The President of the United States appointed, as the American members of the Board, Mr. Hubert R. Gallagher, Assistant Director, Council of State Governments, and Dr. John Van Oosten, Fish and Wildlife Service, Department of the Interior. The representatives of the Canadian Government were Dr. A. G. Huntsman, Consulting Director to the Fisheries Research Board of Canada, and Mr. D. J. Taylor, Deputy Minister of the Department of Game and Fisheries of the Province of Ontario. During 1940-41 the Board held a series of joint hearings at various points on the Great Lakes, 29 in all. Approximately 1,500 persons, consisting of commercial fishermen, sportsmen, conservation officials, state and provincial legislators, and representatives of business firms serving the fishing industry attended and gave testimony at the hearings.

In addition to the hearings, the Board submitted a questionnaire to some 4,000 fishermen on the Great Lakes in order to secure their views with regard to various important questions.

The Board completed its work and submitted its formal report to the two governments on August 6, 1942. The report contained the following recommendations: (1) That there be common investigation of the fisheries of the Great Lakes. (2) That, insofar as investigation shows fisheries to be dependent upon a common stock or to have the same conditions, regulations for management of these fisheries be formulated and tested by a common or joint agency. (3) That where investigations are not conclusive, such common regulations be applied and the results therefrom appraised carefully until there is adequate proof of their effectivenss for the purpose. (4) That the attention of the agencies concerned be drawn to the need (a) for accurate statistics of the take and of the fishing effort, (b) for separate statistics for each species of fish, and (c) for separate statistics for each of such districts as may be defined in common agreement. (5) That thorough tests be made of the effectiveness of planting fish in a lake or lakes in order to determine whether the present planting of fish should or should not be continued or altered.

Atlantic Herring Investigation Committee.—This Committee was established in 1945 to conduct cooperative research for the governments of Canada, Newfoundland, New Brunswick, Nova Scotia, Prince Edward Island, and Quebec. At present its work is directed particularly to the study of the herring populations in the Gulf of St. Lawrence and adjacent waters.

Cooperative Investigation of the Fisheries of the British West Indies.—From October 1943 to December 1944, the U. S. Fish and Wildlife Service cooperated with the British Colonial Government, the Foreign Economic Administration, and the Anglo-American Caribbean Commission in the conduct of a fishery survey of the islands of the British West Indies. The objective was to provide means and to recommend procedures for increasing fishery production in the area, to relieve serious shortages of protein foods. Although the need for this assistance was associated directly with the war because the Caribbean area was unable to obtain supplies of salt fish from the United States, Canada, and Newfoundland, it now appears that the area must revise its food habits in order to face new developments in the fishing industry. The salt-fish industry of New England is now of minor importance. The technological advances of Canada and Newfoundland have diverted fish catches away from the salted product into fresh and frozen commodities. The export trade in fishery products of Canada and Newfoundland during the post-war period probably will consist only to a minor degree of salt fish. Therefore, the Caribbean area must produce more fresh fish locally to meet immediate needs and must also provide facilities for handling fresh and frozen fishery commodities in the consuming areas. The report of the cooperative survey contained recommendations and opinions which involved the introduction of new types of gear and the utilization of new species which hitherto had not been used for food. Some successful experimentation was conducted with gill nets, trolling, long lines, and modified otter trawl.

Cooperation with the American Republics.—The Fish and Wildlife Service of the Department of the Interior is a regular participant in the program of the United States Government for cooperation with the other American republics, which is conducted under the auspices of an interdepartmental committee established by the Department of State and financed by Department of State appropriations. These cooperative projects are authorized by the Act of May 3, 1939 (5 U. S. C. 118e) and the Act of August 9, 1939 (22 U. S. C. 501). These laws authorize the detail of experts of the United States to assist foreign governments with certain scientific and technical projects upon their request, and also authorize agencies of the Federal Government to cooperate with the corresponding agencies of the governments of the other American republics in scientific and cultural projects of mutual interest and concern. The Fish and Wildlife Service has participated in this program since 1940, and during the period has supported the Mexican Fishery Mission as a continuous project.

This Mexican Mission consists of two experts assigned by the Fish and Wildlife Service, who are assisting the Mexican Government in investigating, developing, and conserving the marine fisheries, and in surveying the interior waters of the country, establishing a fish-stocking policy, and constructing and modernizing the fish hatcheries. During the past year, an additional undertaking has been the development of a farm-pond program for warm-water fishes similar to that conducted by the Fish and Wildlife Service in cooperation with the Soil Conservation Service in some of the southern states. The Fish and Wildlife Service has provided a fishery mission to Peru in 1941; a fishery mission to Venezuela in 1942; and a fishery mission to Chile in 1944 and 1945. These three missions were for the purpose of giving technical assistance to the governments concerned in developing their fishing industries and in surveying their fishery resources in order to establish conservation and management programs, so that maximum utilization consistent with preservation of the resources could be established and maintained. During 1946, at the request of the Guatemalan Government, the Fish and Wildlife Service undertook a survey of the fishery, migratory bird, and mammal resources of Guatemala, which will be concluded in 1947. During the fall of 1946 the Fish and Wildlife Service will begin a 1-year cooperative survey of the interior fishery resources of Bolivia for the purpose of developing plans to utilize the tremendous populations of lake trout that have developed in Lake Titicaca from plants of lake trout introduced from the Great Lakes several years ago. In addition, the survey will consider other fresh-water lakes and also the streams of Bolivia for the purpose of developing stocking policies and artificial-propagation programs. The modernization of three existing hatcheries is contemplated as a part of the program. The Fish and Wildlife Service has requests for similar projects transmitted by the governments of Colombia, Nicaragua, and Venezuela, which will be undertaken as soon as funds and personnel become available.

Training Grants for Students from the American Republics.—Under the program of the United States Government for Cooperation with the American Republics mentioned above, the Director of the Fish and Wildlife Service has, since 1943, awarded training grants to qualified students from the American republics which entitle them to receive technical training and practical experience in the United States, in fishery sciences and wildlife management. Grants are now being offered in fish culture, fishery biology, fresh-water fishery management, fishery economics, fishery technology, management of injurious wildlife, wildlife conservation, and control of harmful pollution. Students have already been trained from Mexico, Brazil, Cuba, Chile, Haiti, and Peru, and additional grants are being made for the coming year from eight South American countries. These students are placed in offices, laboratories, fish hatcheries, or field stations of the Fish and Wildlife Service where they work on assigned technical projects with staff members of the Service. They also receive an opportunity to pursue part-time course work in universities and colleges where such institutions are affiliated with or in close proximity to establishments of the Fish and Wildlife Service. These training grants provide an opportunity which is non-existent in the American republics for students to receive training in fishery and wildlife technique. It is making a substantial contribution to the advancement of the cause of conservation and technical research in the neighboring countries to the southward.

Chinese Student Training Program.—Although not a part of the program of Cooperation with American Republics, the Fish and Wildlife Service cooperated during 1945 and 1946 with the former Foreign Economic Administration and the International Training Administration by providing technical training in fisheries to a group of five Chinese students. These men completed the 1-year course in July 1946, and have returned to China where they are being assigned responsible positions in the program of the Government of China, for the economic rehabilitation and development of the fisheries of that country. Since the marine fisheries of China have long been in areas occupied by the Japanese, the task of developing those fisheries presents a formidable problem. It is hoped that the small nucleus of personnel trained in the United States will provide some competent guidance in the necessary program of reconstruction.

Rehabilitation of the Philippine Fisheries.—The fisheries of the Philippines, one of the chief sources of protein food for the Islands, were totally demoralized by combat and by Japanese expropriation of vessels and other equipment. Prior to the war, the fishery activities of the Filipinos themselves were limited largely to inshore waters, and to an extensive program of pond-fish culture. The very productive off-shore fisheries were prosecuted largely by alien Japanese interests and Japanese vessels and crews. On account of the urgency of reestablishing food production in the Philippines, the President of the United States on October 5, 1945, ordered the Secretary of the Interior to conduct a survey as to the nature, extent and cost of a program of rehabilitating the Philippine Island fisheries. The Fish and Wildlife Service, in March 1946 undertook this survey with the aid of the Navy and the Army, who received instructions from the President to cooperate. This reconnaissance survey, concluded in August 1946, furnished information as to requirements of fishing gear, vessels, and facilities for the establishement of the fishing industry.

The Philippine Rehabilitation Act, approved by the President on April 30, 1946, provided for the conduct by the Fish and Wildlife Service, during the period between the date of enactment and June 30, 1950, of a research and development program for the Philippine fisheries. This program, which is to get under way during the late fall of 1946, will consist of oceanographic, biological, experimental-fishing, exploratory, and technological investigations of the fisheries, and of market developments and other economic studies essential for the development of the industry. In enacting legislation, it is the desire and intent of Congress that the Fish and Wildlife Service shall assist the Philippine Government in developing a substantial offshore fishing industry to replace the former industry prosecuted by alien Japanese interests. As part of the program, the Fish and Wildlife Service is authorized to give training in deep-sea fishing and other techniques to not exceeding 125 qualified Philippine students. Execution of the program will involve the construction of a permanent laboratory in the Philippine Islands and also the acquisition, conversion, and operation of a fleet of research and experimental fishing vessels. The result of the 4½-year program will not only be of great assistance to the Filipinos in developing their own industry, but also will provide fundamental information concerning the fishery resources of the South Pacific which may be useful to American fishing interests who may wish to operate in the area.

Economic Survey of the Mandated Islands.—The Fish and Wildlife Service is cooperating with the United States Commercial Company, a subsidiary of the Reconstruction Finance Corporation, in an economic survey of the mandated islands in order to determine how industries and enterprises may be developed for the advancement of the citizens of those islands. The Fish and Wildlife Service is cooperating to the extent of the loan of its personnel, who are surveying the possibilities of prosecuting the fishing industries in the various areas. This survey is scheduled for completion in October 1946.

North American Council on Fishery Investigations.—The North American Council on Fishery Investigations has held no meetings since 1939. At the present time no decision has been reached by the governments concerned as to whether the work of the Council should be revived.

International Council for the Exploration of the Sea.—Because of the war the International Council for the Exploration of the Sea had been forced to suspend meetings since 1939. On October 15–20, 1945, the Council held its 33rd meeting at Copenhagen, at which time it heard reports of the various committees and made arrangements with regard to budget and program which had long been held in abeyance due to the lack of formal meetings. At this meeting it was unanimously voted to extend invitation to membership to the United States of America, Canada, Newfoundland, and the Union of Soviet Socialist Republics. It is understood that the United States, Canada, and Newfoundland informed the Council that they would be unable to reach a decision as to membership immediately. Thereupon, the Council invited the United States, Canada, and Newfoundland to send observers to its meeting which convened in Stockholm, Sweden, on August 12, 1946. Mr. Elmer Higgins of the Fish and Wildlife Service and a representative of the American Legation in Stockholm were designated as observers by the United States Government. Dr. John R. Dymond, Director of the Royal Ontario Museum at Toronto, was designated as observeer on the part of the Canadian Government. The Newfoundland Government did not send an observer. At the time this report is prepared no information is available as to the proceedings at the August meeting.

International Overfishing Conference and Convention.—An International Conference met in London at the invitation of the government of the United Kingdom on March 25 and terminated its meeting on April 5, 1946. Delegates at the conference were sent by Belgium, Denmark, Eire, France, Iceland, Netherlands, Norway, Poland, Portugal, Spain, Sweden, United Kingdom, and observers were present on the part of the United States of America and the International Council for the Exploration of the Sea. The delegates signed a convention for the Prevention of Overfishing on April 5, 1946, the principal provisions of which are as follows: (1) The Convention applies to all waters within those parts of the Atlantic and Arctic Oceans and their dependent seas which lie north of 48° North Latitude and between 42° West Longitude and 32° East Longitude, but excluding the Baltic Sea and belts lying to the south an east of lines drawn from Hasemoren to Gniden Point, from Korshage to Spodsbierg, and from Gilbierg Head to the Kullen. (2) No vessels shall carry on board or use any trawl, seine, or other net towed or hauled at or near the bottom of the sea which has meshes less than those prescribed by the Convention. (3) No fish shall be caught or retained on board of the descriptions and of sizes less than those prescribed for each fish. (4) Contracting governments undertake to prohibit the landing, sale, or offering for sale, of any fish of a lesser size than prescribed by the Convention. (5) Scientific fishing operations are exempted from the provisions of the Convention, but any fish taken in the course thereof cannot be sold. (6) The contracting governments agree to establish a permanent commission to which each may appoint one, or if they desire, two delegates. (7) The commission is to work in close collaboration with the International Council for the Exploration of the Sea and is to advise from time to time as to whether any regulations contained in the Convention should be modified.

The United Nations Food and Agriculture Organization.—On the invitation of the United Nations Interim Commission on Food and Agriculture, which was established as a result of the Hot Springs Food Conference of 1942, representatives of the United Nations met in Quebec on October 16, 1945, to sign the constitution of the Food and Agriculture Organization of the United Nations and to hold the first session of the Conference. The following governments signed the constitution, thus bringing the Food and Agricuture Organization into existence: Australia, Belgium, Brazil, Canada, China, Colombia, Cuba, Czechoslovakia, Denmark, Dominican Republic, Egypt, France, Greece, Guatemala, Haiti, Honduras, Iceland, India, Irak, Liberia, Luxemburg, Mexico, Netherlands, New Zealand, Nicaragua, Norway, Panama, Peru, Philippines, Poland, Union of South Africa, United Kingdom, United States, and Venezuela. The following governments were admitted as new members during the Conference: Lebanon and Syria. The following governments eligible for original membership accepted the constitution and thereby became members: Bolivia, Chile, Ecuador, Paraguay, Uruguay, and Yugoslavia. The Union of Soviet Socialist Republics was represented at the Conference by an observer. The membership of the United Nations Food and Agriculture Organization at the close of the session in Quebec consisted of 42 countries. Of especial interest to the American Fisheries Society are the recommendations of the Quebec Conference with respect to fisheries: (1) FAO should include provisions for exchange of fishery publications between various countries; (2) arrange for publication of a classified catalogue of existing fishery data; (3) encourage agencies publishing reports relating to fisheries to print summaries so that the report may be utilized more easily by research workers; (4) arrange eventually for the publication of digests of new and important contributions to the knowledge of fisheries; (5) encourage the collection and publication by member-nations of basic fishery data; (6) arrange for the early publication of nomenclature and synonyms of economically important species of fish; (7) arrange for a conference looking toward a uniform method of collecting and reporting fishery statistical data; (8) encourage, as soon as possible, the resumption of suspended or curtailed biological and hydrographical research in fisheries; (9) emphasize the need for continuous fishery investigations to maintain at all times knowledge of the condition of the resources as a basis for perpetuating sustained production; (10) encourage exchange of information on current activities and cooperation and research by nations that share the same resources; (11) stimulate the provision of better research facilities; (12) encourage the exchange of students and research workers among nations; (13) encourage the use, to the fullest extent, of present information on the nutritional value of fishery products, and the results of these studies, as they are completed, in order to popularize fish as an excellent source of protein food, minerals, and certain of the essential vitamins; (14) encourage studies to bring about increased consumption of fish, particularly where the present diet consists largely of cereals and pulses; (15) encourage the exchange of information on the most satisfactory and attractive means of preparing fish for culinary purposes; (16) encourage research on the development of pharmacological products in order to diversify further the uses of fishery products; (17) secure the adoption of improved methods which have been or will be developed, possibly achieving this end through the establishment of some form of clearing house for periodic reports on research, and on relevant patents, thus making available up-to-date information on the scientific handling of fishery products; (18) sponsor periodic international conferences of fishery technologists to discuss the problems arising in the various countries; (19) encourage, through cooperation with the interested international and national bodies, further development of existing research centers and the establishment of new centers in the major production regions and in areas where fisheries might be more fully developed; (20) cooperate with international bodies such as those concerned with labor, health, and education to encourage the initiation of studies on such projects as the relation of fishery methods to production and employment, to the general well-being and public health, to occupational hazards and diseases, and to opportunities for education and community life; (21) encourage the primary fish-producing and fish-consuming nations to undertake studies in the field of fishery economics which should extend not only to the economics of production, processing and distribution, but also to consumption; (22) FAO should encourage the establishment of fishery schools and suitable fishery courses at appropriate institutions. Agricultural schools, in many countries, could serve as training centers for persons specializing in fisheries and could also serve as centers for specialized fishery courses, and for extension work and the dissemination of information to fishermen and shore workers on all phases of fishery production, processing, and distribution; (23) stimulate interest in fishery research in the field of conservation; (24) encourage international forums of cooperation and management with a view to greater utilization of fishery resources; (25) cooperate for the foregoing purpose with other international bodies concerned with fisheries; (26) explore the possibilities of eventually coordinating the activities of international organizations under the auspices of FAO; (27) invite member nations to consider the desirability of arranging periodic conferences between regional authorities, including established national and international councils for the study of the sea; (28) lend all possible support to the development of international programs of cooperative research and wherever necessary suggest regulatory action, on a regional basis, to conserve and bring about the proper management of fishery resources; (29) encourage the full exchange directly or through FAO of information relating to the advances of design in fishery craft and fishing gear; (30) encourage practical demonstrations of modern fishing vessels and fishing gear; (31) encourage the adoption of suitable techniques of fish culture wherever facilities and conditions for the propagation of fish render such programs practicable; (32) encourage governments to grant credit to assist technical agencies and to be prepared to give expert advice when it is required; (33) offer to the international banks for reconstruction and development, services regarding credit in the case of fisheries similar to those contemplated for agriculture; (34) study the possibilities of commodity arrangements as they affect fisheries, particularly as they promote or hinder better orientation of production and as they may be effective in providing opportunities for supplying consumer markets from the most efficient sources of production; (35) study, as the integral part of the fishery program of FAO, the effects of tariffs and other international barriers on world trade, as well as the effect of a normal fluctuation in the exchange rate which restrict the production, distribution, and consumption of fishery products; (36) furnish such information to the governments of producing and consuming countries and to other interested authorities.

FAO held a special meeting on urgent world food problems in Washington, D. C., May 20–27, 1946. So far as fisheries are concerned, the conference considered statements concerning unsold supplies of fish and fishery products, mainly in certain European countries, which have accumulated due largely to the lack of transportation facilities on the European Continent. It also considered the fact that more herring could be caught and a larger portion of European herring catches diverted from industrial to human use if secure markets could be found. The conference also recognized that any efforts to increase fishery supplies during the year following the conference and to expedite the rehabilitation of fishing fleets invitably would raise wider issues affecting the long-term prospects of the fishing industry. It was then concluded that FAO should undertake a study of long-term fishery problems, including impediments to international trade in fish and fiishery products, the dangers of overfishing, and the possibilities of over-investment in fishing fleets and fish-producing facilities.

The Food and Agriculture Organization is holding its second annual conference in Copenhagen at the present time; no report concerning proceedings is yet available.

Policy for Administering Japanese Fisheries.—The Allied Control Council for Japan has permitted some resumption of the Japanese fisheries, following the surrender of Japan in August 1945, but only pursuant to the following policy and principles developed by the State-War-Navy Coordinating Committee after consultation with other Government agencies: (1) To meet domestic consumption requirements, by insisting that the Japanese Government rehabilitate production facilities of the fishing, fish fertilizer, and seafood processing industries, and facilities for distribution of their products. (2) To look to coastal fisheries and fish culture as primary sources for domestic consumption. Only to the extent that the foregoing are unable to meet minimum domestic requirements, permit deep-sea fisheries and other fisheries in water open to Japanese operation where allowed by security and political considerations. (3) To have Japanese fishing operations conform strictly to the provisions of agreements relating to whaling and conservation to which the United States is a party, and to Japanese national and local regulations for the conservation of fisheries. (4) To export such fishery products not suitable for or convertible to use in domestic consumption, and which are needed (a) to supply United Nations needs for animal proteins and oils, or (b) to secure foreign exchange for essential imports.

MR. WESTERMAN: Mr. Herrington raises a question that might well be considered by the membership—whether the report of this committee is sufficiently important to justify the time and effort necessary to its compilation.

THE PRESIDENT: Mr. Herrington had to cover many years, and much has happened in the international field in the meantime. Personally I think it is well to have the report printed in the record.

DR. DEASON: I disagree with Mr. Herrington's suggestion as to the value of these reports, and especially as to the part the Society can or does play in the field of international relations. We have in the recently concluded Great Lakes treaty a concrete example of what can be done by the interest of organizations such as the American Fisheries Society. I am confident that the resolutions passed by this Society and other organizations from year to year recommending the adoption of some coordinated method of management of the Great Lakes fisheries were a factor in bringing about that treaty.

DR. GOWANLOCH: I should like to confirm Dr. Deason's point of view. I happened to represent Louisiana several weeks ago at the Council of State Governments in an exploratory hearing involving jurisdiction over coastal waters. A report of this type is of the profoundest value. We are at present in an extremely critical situation. I would say that an accurate presentation of the status of international relations is of immense value at this time—more so than ever before in our history.

MR. BUTLER: Hatchery workers in isolated places read these reports. They offer one of the few channels through which they can be brought in contact with far-reaching foreign relations.

DR. CARLANDER: These reports are of great assistance in following international relations. They are one of the few sources of information on what is happening in that regard, and what has happened in the past.

THE PRESIDENT: I wish Mr. Herrington were here himself. Personally I regard these reports as of the greatest value.

COMMITTEE ON STATE AND NATIONAL RELATIONS

JOHN GOTTSCHALK

The several states and the provinces of Canada, and the Federal and Dominion governments of the United States and Canada, have during the past 5 years subjugated whatever differences they may have had to the press of the war emergency. In this time we have seen close cooperation among the states and the provinces on the one hand, and between the federal and dominion governments on the other. Fishery personnel everywhere joined in the war effort. Conspicuous, during the later stages of the conflict at least, were effective cooperative efforts to encourage and develop the productive capacity of the continent for food fish.

With the resumption of peacetime activities, and with full realization of the problems of drastically increased fishing pressure and the resultant need for closer state-federal relations, we consider that there are at least five significantly important aspects of this subject.

Most prominent among these is the new wildlife coordination act, recently passed by the Congress and approved by the President. This bill as approved calls for a highly coordinated approach to the appreciation of fish and wildlife potentials in water-development projects. It is the desire of your committee to emphasize the revolutionary trend exhibited in this act. We believe that the promise offered in this legislation can be realized only by a readiness on the part of the states to accept their responsible duties; and that the Department of the Interior, through the Fish and Wildlife Service, should make known to the states its policy covering the directives of this act at the earliest possible moment. Further, we believe that the states should begin to think seriously about the very great problems of fishery management which will arise in connection with these projects, particularly those which relate to the regulation, and in some cases the encouragement of the harvest of fish from these "created" bodies of water. The matter becomes of specific interest to this committee when the question of harvesting from federally-owned or controlled reservoirs arises; and is strictly comparable to the similar problem in the field of wildlife management wherein there is an annual harvest of fur animals from federally-managed properties.

It is expected that within a year or two the so-called Robertson bill, H. R. 7104, formerly known as the "Buck Bill," will have been passed by Congress and approved by the President. This legislation, vital and important as it is, can be expected to create the same general types of problems in state-federal relations that have arisen from the operation of the Federal Aid Program in wildlife restoration. Even now the formula for the apportionment of funds under the act is subject to question, particularly by those states which have separate hunting and fishing licenses as well as combined licenses.

Efforts of the states bordering the Great Lakes, and the Province of Ontario, to regulate the take of commercial fish under uniform regulations have been the subject of discussion, argument ,and resolution for many years. All those efforts aimed at the achievement of such regulations by interstate agreement have met with discouraging failure. Now a treaty between the United States and Canada has been drawn up for the purpose of providing such regulations, as well as the investigations upon which these regulations will be based. As yet the treaty has not been ratified by the Senate, but it will be reintroduced for consideration at the next session of Congress.

There has been almost universal improvement in the cooperation between the states and the federal government in the matter of fish-stocking programs. In some instances this cooperation extends to the virtual exchange of distribution equipment, and, indeed, represents a salutary improvement over conditions existing a decade ago. There are undoubtedly situations in which further collaboration will improve the effectiveness of those management programs utilizing fish for restocking purposes.

Throughout the continent there has been a slow awakening to the relation existing between land use and fish conservation. Although the matter far transcends the importance of fish life, it has assumed immediate import for fishery people in connection with the initiation of attempts to place in the hands of a few individuals a large portion of the public domain now used under the permit system for the grazing of livestock. The western states are specifically interested in the ultimate effects of this trend upon their wildlife and fish, and we believe it to be so dangerous that it should be brought to the attention of this meeting.

COMMITTEE ON COMMON AND SCIENTIFIC NAMES OF FISHES[1]

WALTER CHUTE

The Committee on Common and Scientific Names of Fishes was originally appointed in 1933. It failed to funtion during the first 5 years of its existence and was reorganized at the 1938 meeting. The following year work on the project was started under the present Chairman.

A preliminary canvass of the committee members resulted in the following rules of procedure:

1. Only one common name to be accepted for each fish.
2. Any common name receiving a two-thirds vote of the committee members to be accepted.
3. The word "common" in connection with a fish's name to be avoided whenever possible.
4. The common name to be simplified, omitting hyphens, suffixes, . . . , except where they have a special meaning.
5. The entire list to be completed before submission to the Society, rather than piece-meal submission as the work progressed.

Considerable objection was raised to the two-thirds-vote rule, on the grounds that the committee of seven was too small to cover adequately the entire area under consideration and that it was not geographically well-balanced. It was decided therefore to consult with a number of other workers in various sections of this country and Canada, and accordingly some 25 other authorities were contacted. Nineteen responded, making a total of 26 persons engaged in this project.

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[1] The present report is an interim statement of progress. Because of excessive delays in the publication of the TRANSACTIONS and the urgency of making the materials available to the public at the earliest possible moment, the final report of the Committee, presented at the Seventy-seventh Annual Meeting, was issued as an independent publication (Special Publication No. 1) and subsequently reprinted as an appendix to Volume 75 of the TRANSACTIONS.

The original list of 439 fish names was sent out in three sections, one for the Atlantic, one for the Pacific and the third for fresh-water fish. Suggested additions soon raised the list to over 600 names. Some of these have been deleted as varieties or because they were not considered by the Committee to be of sufficient importance to be included. Others have been suggested, however, that have not yet been submitted to a vote, so that the number still under consideration remains about 600.

The use of three separate lists proved to be unsatisfactory, as many of the collaborators ignored those lists not applying to their particular section, despite the fact that there were duplications in common names between the various sections that needed a deciding vote one way or the other. It was therefore decided to combine all the names into one list in systematic order and resubmit it to the enlarged Committee. The Chairman was engaged in preparing this list when forced to suspend work on account of the war. Many of the cooperating workers were called to other duties, some of them outside the country, and the Chairman, faced with the difficulties of operating a non-essential institution with inadequate personnel, was forced to abandon all work on this project. It was not until this past summer that it has been possible to take up the work again.

In the beginning it was evident that it would be impossible to secure a unanimous vote on more than 50 percent of the names on the list. It was hoped, however, that a two-thirds agreement could be reached on the others. The Committee now has 504 names that have received the necessary two-thirds vote, and these will be considered as settled. There are still some 40 names on which there is a wide disagreement among the enlarged Committtee and, unfortunately, these 40 include some important fish, such as the chub or cisco of the Great Lakes region, and the kingfish or king mackerel of the Atlantic. It is interesting to note that the controversial list still includes the fresh-water sculpin or bullhead, a misunderstanding over which was responsible for the resolution at the 1933 meeting which originated this project. There are also about 45 additions proposed, which have not yet been submitted to a vote.

As this work has progressed it has become evident that even a two-thirds agreement on the controversial names is impossible. Therefore, it is now proposed that those names still in controversy be submitted to the members of the official Committee and a majority vote of this Committee be taken to settle the issue. Unless this procedure is adopted it is feared that work will go on endlessly. At the same time a vote will be taken on the 45 new proposals.

Working with the official Committee of seven members there is no reason why this final vote should not be received early next year so that the completed list will be ready for submission at the 1947 meeting.

When and if the completed list is accepted by the members of the American Fisheries Society, two indexes will be prepared to accompany it when published in the TRANSACTIONS—one index for specific names and the other for common names. The latter index will endeavor to list all the common names in general use and indicate the name accepted by the Society, together with acceptable secondary names and all other names used generally but not considered acceptable or proper.

It is recognized that the completed list as now visualized will not meet the unanimous approval of the members. The Committee has tried to be consistent and select only those names that identify the various fish correctly, both systematically and geographically. It has been compelled to make some exceptions, however, for various good reasons. The Committee feels that with 90 percent of the names on the list receiving a two-thirds or better agreement and the balance decided by majority vote, the resulting list will be as nearly authoritative as can be expected and will help considerably to lessen the present confusion in common names of fishes.

Considerable pressure has been exerted on the Chairman of this Committee to secure some action on this project. President Van Oosten has urged repeatedly that some form of list be presented, even though it contained only those names that had been agreed upon. This the Chairman was loath to do, as the Committee was agreed that the presentation of a partial list containing names that might have to be changed in the light of future decisions would only add to the confusion. The Chairman regrets exceedingly that conditions beyond his control forced such a long delay in this project. Now, however, that the work has started again, he predicts that regardless of what the Society decides to do in regard to the personnel of this Committee, a completed list will be presented at the next meeting and if accepted, will be ready for publication in the TRANSACTIONS of that meeting.

COMMITTEE ON PUBLICATIONS

H. J. DEASON

Following the publication of Volume 71 of the TRANSACTIONS, which contained the proceedings of the 1941 meeting at St. Louis, it was necessary to adopt a new procedure to ensure the submission of sufficient manuscripts to justify the publication of the TRANSACTIONS during the war period when annual meetings of the Society were not held. With the approval of the Executive Committee the Committee on Publications solicited manuscripts by direct correspondence with individual members, and thus the publication of Volumes 72 and 73 has been made possible. We believe that despite the necessity for soliciting manuscripts, Volumes 72 and 73 compare favorably in size and in quality with previous volumes, thus maintaining the standards of the journal as a scientific publication on fisheries. The same procedure has been followed with reference to Volume 74, which is now in the hands of the printer and should be out of the press before the end of the current calendar year.

The Executive Committee has promised the members that one volume of good scientific and practical papers on fishery subjects would be published to correspond with each year during which no meetings were held. As has been said, Volume 72, for 1942, and Volume 73, for 1943, are already published and in your hands. Volume 74 for 1944 is now in press. The proceedings of this meeting will be published as Volume 76, There then remains the publication of Volume 75 from manuscripts not on the program of this meeting, but which are to be submitted voluntarily by the membership. Only about three or four manuscripts are now in sight for Volume 75, and at least 20 are necessary to justify publication of a volume of minimum size. Therefore any member who has a paper completed, or so nearly finished that he can complete it within 60 days is urged to do so. If any of you know of actual or potential manuscripts which might be contributed by members who are not at the meeting, it is hoped that you will urge them to complete and submit their manuscripts for publication in Volume 75.

During the war period and the shortage of materials for publication the Committee has been urged to accept papers that were far below the minimum standards of quality which have been established by the Society in recent years. The Committee has refused to relax those standards. Instead it has done its utmost to solicit and publish outstanding papers in the field of fisheries. It has endeavored also to obtain papers that would serve to broaden the scope of the subject matter of the TRANSACTIONS; and I refer in this connection to certain papers that appear in Volumes 72 and 73 on marine and anadromous species. Our TRANSACTIONS do not generally contain papers on marine fisheries. The Society has been endeavoring for years to attract members active in marine fishery work. Our best means of doing so I believe is to get a number of marine fishery papers into the TRANSACTIONS every year if possible.

Publication of the volume during the war years has been delayed, not only because of the previously mentioned difficulty of securing acceptable manuscripts, but also because of other circumstances. Our printer, like all the major printing establishments in the United States, was under contract to the United States Government Printing Office to help out with the load of war-agency printing, and such government jobs had priority over all other printing in the contract establishements. Also, two members of the Committee, Dr. Charles M. Mottley and Dr. Justin W. Leonard, were unable to assist during most of the war period because they were helping the Navy and Army respectively, with other matters. Two other members of the Committee had to hold down two positions at one salary during the war period, which meant that the war-agency work was done during working hours and the regular job after hours and on week-ends. The time available for editing the TRANSACTIONS came out hindmost, since even off-duty hours are limited.

Last but not least, some of the delay in publication, as always, was due to the necessity of returning manuscripts for revision and correction—even for corrections that could be attributable only to inexcusable carelessness. I shall not bore you by dwelling any further on that subject; you have heard it discussed at every annual meeting since 1937. Compliance with the instructions for preparing manuscripts is essential if the Committee is to give you a good printing job. If you have not a copy of those instructions and have a paper on the program or intend to submit one for publication, I request that you get a copy; I am leaving a number of them with the Secretary. They will help you and will help us. And please do not give us tables the size of bed-sheets; we do not know what to do with them. A printed page will take only so much matter, regardless of how much you condense it.

The Committee receives criticisms and complaints from members about typographical errors in the final volume. I am sorry those do creep in, but in checking them I have found that many of them are directly attributable to the authors themselves. They have not made the correction in their proof, or have made errors in the original manuscripts which they did not detect until after the volume was published; and then they blame the Committee for it. We are not clairvoyants, and we cannot tell what you intended to say if you do not say it correctly.

Also there are some members who in correcting proofs wish to rewrite or virtually rewrite their papers. This we cannot permit. Your paper is supposed to be a finished piece of work when it is submitted for publication. If you want to make more than minor corrections it may involve scrapping three or four pages of type and setting it over again. This type is not hand-set; it is set on linotype or monotype machines. Substantial revisions on a proof mean that the Society incurs additional expense in printing, and I think it is an injustice to the Society for members to expect that it will bear the cost of scrapping type and the making of major changes in proofs.

With this meeting your Chairman completes his term of service as a member of the Committee. He has enjoyed the opportunity of serving the Society in this capacity. To the present members of the Committee who will continue in service, and to the new members and the Chairman to be appointed, he extends best wishes and condolences—best wishes for the improvement of the TRANSACTIONS that they will seek to bring about—we have gone far, but there is a long way to go—and condolences for the friends they may lose through their public-spirited efforts to improve manuscripts by editing and suggesting revision. It is the same the world over. To many persons an editor is a representative of one of the lower orders of the animal kingdom.

In retrospect it has been interesting to note the number of papers received for publication which in reality are not contributions to science but are actually the application of old techniques to new localities and species with the same results. Such papers have a place in that they add proof or disproof to older conclusions and principles. But we must remember that fishery science is yet young. There are many unknowns but I hope no unknowables in the eyes of Eternity. There is room for many pioneers, and for the broadening of the horizons of fishery research, and I hope that year by year, as I now propose to review the publication of papers as a member only, the TRANSACTIONS will continue to portray and reflect the growth of fishery knowledge.

MR. HIGGINS: I move the adoption of the report, and at the same time move a vote of thanks to the retiring Chairman of the Committee and all members of the Committee, who, as we all know, have labored diligently and well in preparing the Society's TRANSACTIONS for publication. [Motion carried.]

REPORTS OF SPECIAL COMMITTEES

POLLUTION STUDY

KENNETH A. REID

As a background for a thorough understanding of the pollution problem in the United States, we will first give a brief history of the efforts to correct it, state and federal, during the past 25 years, and then review the efforts of the last Congress. We will not burden you with extensive data on pollution itself, for we all know that pollution from domestic sewage and industrial wastes is rampant throughout the United States, and even increasing. The problem for consideration is not to establish the existence of pollution or its dire effects on wildlife, as well as on the human race, but what course is to be followed to correct this deplorable situation of long standing.

In the very first issue of the Izaak Walton League's publication, then called the *Izaak Walton League Monthly,* August 1922, the late Dr. James A. Henshall said in a caption on an article on the subject, "Pollution is the most important problem the Izaak Walton League will have to solve." In the next issue, he said, "Federal control is the only answer."

The League accepted his first challenge and since that time, 24 years ago, has consistently sought through public education, state legislation, and during the last 11 years through federal legislation, to correct the situation. We sought federal control only after it became abundantly clear that state control alone was not the solution. After all the years that the states have had control of pollution by statutes that have been on the books in many cases for upwards of 20 years, it is idle to contend that state control of water pollution is adequate.

The present movement for federal control of water pollution had its inception in the historic Dern-Lonergan Conference, held in the offices of the late Secretary of War Dern in December 1934. I had the honor to be a member of that Conference of so-called experts gathered together from various parts of the country to formulate a workable program to correct the polluted condition of the nation's waterways. A sub-committee was appointed to make its recommendations and submit them to the Conference. When the sub-committee was unable to agree it submitted two reports—a majority and a minority report. Both called for federal legislation and both called for study and investigation and financial assistance from the federal government, but there was disagreement on the matter of federal control. After consideration of both reports, the Conference adopted the report calling for federal control, as well as study and financial assistance.

For more than a year, a special committee appointed by this Conference studied state legislation and federal legislation and other data having a bearing on the subject. On the basis of the facts accumulated, former Senator Augustine Lonergan introduced in March 1936 the first of the present series of federal anti-pollution bills, S-3958. As a result of the hearings on this legislation, industrial polluters and some of the larger offending cities, together with a number of state health officials who put political or petty jurisdictional philosophies ahead of the public desire for clean water, joined forces in a flank-attack movement. This move took the form of some five different bills, all purporting to be pollution-control bills, but not one of which gave one iota of authority to any agency to control pollution. In that session of Congress, the fight narrowed down to a contest between the Lonergan Bill representing the recommendations of the Dern-Lonergan Conference, and calling for federal control of pollution, and the Vinson Bill supported by the major polluters of the country, industrial and municipal, providing only for more investigation.

From that time down to the present, every session of Congress has had legislation before it for the control of water pollution and, opposing it, so-called pollution control legislation, the purpose of which was to act as a dose of soothing syrup on the public demand for action and at the same tim to confuse the public and Congress as a means of preventing passage of actual federal-control legislation,

In the 79th Congress, the Mundt Bill, HR 519, calling for federal control, might be called a direct descendant of the original Lonergan Bill, while the Spence Bill, HR 4070, could be called a direct descendant of the original innocuous Vinson Bill.

In the 1936 hearings, opponents of pollution control said: "This bill is very drastic; you cannot do the thing overnight; give us a little time and we will take care of the problem. We do not need federal law or regulation." I call attention to the fact that it was 10 years ago last March that these statements were made. In the intervening years the original draft has been rewritten and rewritten to take into consideration every legitimate objection that was levelled at the original bill. Yet in this last hearing I heard these same statements; the industry must have time. Well, it has had over 10 years and has done nothing—speaking generally throughout the United States; at any rate the sum total of water pollution in these United States is greater than it was 10 years ago.

The line-up of support and opposition was essentially the same as heretofore; the conservationists supported the Mundt Bill, while the polluters and the apologists for pollution supported the Spence Bill. But there was one significant difference. In the hearings before the Rivers and Harbors Committee last November, the former imposing array of national industrial associations opposing any federal control of water pollution was conspicuous by its absence. In their stead, however, were a number of state health officials who shed crocodile tears over the polluted condition of the nation's waterways, and then exhorted Congress to do nothing about it except spend money for further study and investigation as provided in the Spence Bill.

In closing our testimony, we told the Committee that we didn't care what name or number the bill bore; if Congress in its wisdom preferred the administrative set-up in the Spence Bill to that in the Mundt Bill it was all right with us; and if Congress felt that the 1½-million dollar slush fund in the Spence Bill for the administrative agency to give the state health departments to study and investigate the problems further was desirable, we had no objection (in spite of the fact that the taxpayers of the country spent over $600,000 to make a complete pollution survey of the Ohio River System, 3 years ago, only to see the data go unregarded).

The one point on which we insisted was that any bill passed by Congress should be what it purported to be, namely, a pollution-control bill, not a mere subterfuge which would lead the public to believe something had been done while actually granting polluters a moratorium of 5 to 10 years before the public would awaken to the fact that it had got only another dose of soothing syrup.

We specified our minimum requirements as:

1. Outlawing the spread of pollution from new sources. The first step of the medical profession in dealing with a contagious disease is to quarantine that disease. We must do the same thing in water pollution.
2. Some federal authority, however remote in the background, to bring about the uniformity so essential to make state control effective.

Bearing in mind these two minimum requirements, we suggested the Committee take the three bills before it, study them carefully, select the best features of the three, and write its own bill. The Committee did just that in HR 6024, bearing the name of the Chairman, Congressman Mansfield.

This bill was a composite bill taking from the Spence Bill the United States Public Health Service as an administrative agency, the 1½-million dollar annual appropriation for the administrative agency to give the state health departments for study and investigation, and the loan-and-grant provisions to assist industries and municipalities to clean up their pollution; and from the Mundt Bill the vital enforcement provisions, providing that after existing state or interstate control agencies had demonstrated either their inability or unwillingness to control their pollution the federal authority could intervene.

After analyzing this bill, we gave it our full support and urged all other conservation agencies to do likewise. For the first time in the history of the effort we had before Congress a bill written and approved by the Rivers and Harbors Committee, which merited the sincere support of all those desiring clean water. Also, for the first time, the United States Public Health Service gave its approval to a federal pollution-control measure.

With the coalition of many formerly opposing forces in support of HR 6024, the prospects looked exceedingly bright for its passage during this session. While the inclusion of the 1½-million dollar annual appropriation for study and investigation by the states acted as effective bait to win over the support of some state health departments formerly opposing all federal control, other state health departments and at least one interstate compact continued to oppose the bill. While undoubtedly there was some under-the-cover opposition from the ranks of industry and offending municipalities, we are convinced that the narrow bureaucratic opposition of state health departments and interstate compacts constituted the principal opposition and was primarily responsible for the failure of the bill to pass during the 79th Session.

Weeks and months dragged on while action was deferred. Finally, on July 10 the bill came up, but action was prevented by delaying tactics of two Congressmen from New Jersey and one from Cincinnati, Ohio. As Congressman Karl Mundt so aptly said in the debate at that time, "Those who have long opposed correction of water pollution, having exhausted all valid arguments against such legislation (as they have all been answered in the present legislation), have in despair adopted delaying tactics to prevent this much-needed legislation from coming to a vote."

It was disappointing, of course, that after more than 10 long years we failed to get this desirable legislation enacted into law. But the groundwork laid in this session should pave the way to success in the next. The provisions of HR 6024 merit the support of every decent citizen who believes in the public's inherent right to clean waters. It is very considerate of polluters, both industrial and municipal, giving them ample extensions of time wherever the need for such extension can be demonstrated. It also, in plain English, provides that the federal authority shall not be invoked until existing state or interstate authority has demonstrated either its inability or unwillingness to do the job. State health departments, honestly trying to do a good job, welcome the valuable moral support the bill will give them, helping them to get action on recalcitrants where action would otherwise not be forthcoming. Only those state agencies or interstate compacts that don't intend to enforce their laws against water pollution could possibly have any objection to the bill's very considerate provisions.

Now, I want to talk very frankly and directly to the state officials assembled here. It is obvious that something more than state control is necessary to solve the pollution problems; else, why would we have continuing and increasing pollution? State health departments through their narrow bureaucratic jealousy of their jurisdictional authority have constituted the greatest obstacle to the passage of legislation essential to bring about the uniformity, without which state laws cannot be effective. When a bill so clearly guarantees that the federal authority will not come into the state until the state authority fails, an analysis of support or opposition of the different state health departments is a pretty good barometer of the good and the bad state health departments. A number of good state health departments, that are trying to do the best job they can against the old argument of competitive disadvantage that always militates against state enforcement, supported HR 6024, while those who had been doing the bidding of powerful political influences that don't want interference with their pollution, constituted the opposition. I want to repeat that the greatest obstacle to the attainment of the objective of clean water, which we all desire, is the state health departments falling in the latter classification, and the finest service that you men as state administrators can render to the cause of clean water is to go back to your home states and wage battle with your state health departments.

Many of the state health departments that have shouted loudest about the adequacy of state control and that have actively opposed federal control are themselves offenders in pouring the raw sewage of state hospitals or insane asylums untreated into the state waters. We contend that until the public health representatives themselves have clean hands, they cannot with good grace or any degree of effectiveness induce the municipal and industrial polluters to clean up their mess.

So, my parting remark is to urge you to put pressure on your state health department, first to clean up its own offenses against public decency, then, after it has clean hands, to enforce the state's statutes on water pollution against municipal and industrial offenders, and, finally, to support rather than oppose federal legislation, which without encroaching on state authority will furnish the essential "big stick" to disperse the long effective argument of competitive disadvantage which has these many years largely nullified state enforcement, and thereby make their own job of correcting water pollution by state law immeasurably easier. The old argument of "states' rights" has too long been used to perpetuate "states' wrongs" by polluter-controlled or incompetent state agencies having jurisdiction over water pollution.

We succeeded in the last Congress in getting enacted into law HR 6097 to curb the great dam builders. The job of curbing the great polluters still remains to be done. But if each one of you state administrators will accept the task of making a Christian instead of an apologist for pollution out of your own state health department, so that when HR 6024 is reintroduced in the 80th Congress next January, they will support rather than oppose it, the second important step in rescuing water from the classification of the neglected and abused orphan of the whole natural-resource family will have been accomplished.

That is the important conservation job I would like to assign each one of you. Its completion will mean an increased mileage of fish-producing water that will do far more to increase both the opportunity for and the quality of public fishing than the combined efforts of all your production plants and other artificial means. The answer to improved fishing lies in enlarged and improved aquatic habitat—not in expanded artificial production. The answer to enlarged and improved habitat is the passage of federal-control legislation, such as HR 6024, which will provide the uniformity essential to make state-control laws operative. As Chief Justice

Holmes once said, "The only thing that makes taxes bearable is their uniformity." We say the only thing that will make pollution control effective will be it uniformity, and the only way that can be achieved is by federal law. Let's quit talking about it. Let's do the obvious to get the job done.

When we assemble again next year, I hope each one of you can report that you have done your job back home. If you have, I can assure you that the type of federal control bill that the conservationists have long desired will pass in the next Congress.

A SUMMARY OF HR 6024

Section 1. Administrative Agency, the U. S. Public Health Service, Surgeon General, shall prepare comprehensive programs for eliminating or reducing pollution.

Section 2. Encourages cooperative activities by states; uniform state laws; interstate compacts, collection, and dissemination of information, . . .

Section 3. Consent of Congress for two or three states to negotiate agreements or compacts.

Section 4. Public Health Service on request of state shall conduct investigations, surveys, . . . and make recommendations for correction of situations, when such investigation is approved by Surgeon General.

Section 5. Provides for publishing reports of surveys, . . .

Section 6. Authorizes Federal Security Administrator to extend loans, and grants-in-aid to public bodies up to 33 1/3 percent of a responsible cost.

Section 7. Authorizes loans to industry.

Section 8 (a). Establishes a water-pollution advisory board composed of representatives of the Surgeon General, Departments of War, Interior, Commerce, and Agriculture. Reports, examinations, plans, grants-in-aid or loans reviewed by the Surgeon General.

Section 8 (b). Surgeon General to set forth order or sequence of priority for individual projects in accordance with their public benefits.

Section 10. Authorizes appropriations not to exceed $100,000,000 for any fiscal year for grants-in-aid and loans.

Section 11 (a). Authorizes $1,500,000 to be allotted and paid to state health authorities or interstate agencies for studies and investigation.

Section 11 (b). Authorizes an annual appropriation up to $1,500,000 to administer provisions of the Act.

Section 12. Provides: (a) for the appointment of up to five engineer and scientist officers by the U. S. Public Health Service; (b) for utilizing services of officers and employees of other Federal agencies; (c) for use of existing government facilities for reviewing title, location, plans, specifications, . . .

Section 13 (a). Provides for classification of navigable waters and establishment of sanitary water districts; (b) authorizes establishment of standards of cleanliness for each such district.

Section 14. Is practically a verbatim copy of the enforcement authority in the Mundt Bill and, is therefore reproduced herewith in its entirety:

"Pursuant to the powers of the United States to regulate interstate commerce and navigation; to extend, change, and amend the admiralty and maritime law; to give due effect to the migratory bird treaties; and to protect the fisheries, Congress hereby declares the discharge or deposit directly or indirectly of any waste or other substance (whether in a solid, gaseous, or liquid state) which is or may be injurious to human health or to any form of life including aquatic life or to migratory birds as defined in the Migratory Bird Treaties of August 16, 1916, and of March 15, 1937, or impairs in any manner the utility of such waters for navigation purposes, except the normal discharge of sewage from toilets or galley sing drains of boats or of oil from the exhaust pipes of motorboats, into any of the navigable waters of the United States in violation of regulations prescribed by the Surgeon General under section 13 (b), to be against the public policy of the United States and to be a public and common nuisance. An action to prevent or abate any such nuisance shall be brought in the name of the United States by any United States attorney when requested to do so by the Surgeon General. Such action may be brought only upon request of the Surgeon General, shall be brought as an action in equity, and may be brought in any court of the United States having jurisdiction to hear and determine equity cases."

Section 15. Practically reproduces the language of Section 5 of the Mundt Bill. Declares it the policy of Congress to encourage state and interstate agencies and other public bodies to exercise their statutory authority to prevent and abate water pollution, and that the federal authority will be invoked only after interstate, state, and local authorities have been afforded an opportunity to prevent or abate such nuisance, and have failed to do so within 6 months after receipt of written notice.

Section 16. Gives a 2-year moratorium on existing pollution, but excludes new sources of pollution from such moratorium by specifying that this 2-year stay applies only to wastes discharged "prior to the date of the enactment of this Act."

Section 17. Carries the provisions of the Mundt Bill in providing for extensions of time on showing of due cause at a public hearing. First extension limited to 5 years and any further extension contingent upon showing of cause at another public hearing—essentially the same provisions as the Mundt Bill.

Section 18. Provides that any section held to be invalid shall not affect the balance of the Act.

Section 19. Describes the various terms used in the Act.

Section 20. Reads, "This Act may be cited as the 'Water Pollution Control Act'." We agree that it merits the title of a control act.

Dr. Swingle: We cannot very well digest what is in the bill from a reading of a summary. However I would like to bring up one question. In the section on enforcement I believe the bill provides that delivery into a stream of material which would be a disadvantage to navigation, and so on, shall be a misdemeanor. Does this include soil erosion, and if so, does the bill mean that if a farmer's land is washing into a stream he may receive notice to abate this nuisance within a certain period of time?

Mr. Reid: I thing you would have to ask an attorney for an exact interpretation of that point. It was not meant to include soil pollution.

Mr. Funk: There is a section in the bill which prescribes the standards to be set up for pollution. These standards should cover the point brought up by Dr. Swingle.

Mr. Reid: The purpose of the establishment of standards of purity or cleanliness is to take care of different conditions. For instance, the standards in the Delaware River or the Monongahela or other vilely polluted rivers should not be the same as those for a clear and practically unpolluted stream. They cannot be the same for a river that is already fishless and will support no aquatic life, and one which is perhaps mildly polluted but still rich in aquatic life.

Mr. Gordon: In the new Pennsylvania political campaign this fall one candidate is running primarily on the necessity for cleaning up the state's water supplies for the various uses for which they are needed. Conditions have reached the point where the people are demanding that we no longer dawdle; they want us to do some work. The candidate as former Attorney-General gave leadership to the campaign during the past 4 years.

MR. KRUGER: I live in Baudette, Minnesota, on the Rainy River, which is international water. In addition to the ordinary pollution problem we have the problem of our river being contaminated by industrial waste, such as the pulpwood wastes and human waste from two communities 75 miles to the east of us. The pollution is affecting us to the extent that the people in the area of the Ten Thousand Lakes have to buy drinking water. I would like to inquire what steps the Committee propose to take to help us in our plight. We have not only from the United States side but also from Canada, which makes it somewhat of an international problem. Perhaps Mr. Reid can give me some assistance or enlightenment.

MR. REID: I certainly agree that the matter deserves the action that Mr. Kruger suggests. The pollution on the Rainy River is not only practically ruining the Rainy but also is having a dire effect on the great recreational area known as the Lake of the Woods. The Fish and Wildlife Service has made a survey of that situation and published a report on it, pointing to the dangerous condition that exists; the problem is not only national but international. There I presume control of pollution would have to be worked out by agreement or treaty with the Dominion of Canada because both the United States and Canada are involved.

MR. GORDON: At its business session the other day the International Association without reservation went on record as favoring the Mansfield Bill and pledged the support of all the states that are members of that Association. I hope that the American Fisheries Society will take similar action.

DR. GOWANLOCH: I should like like to cite a specific example in Louisiana where in the course of production of oil, pollution occurs. We need every possible instrument to fight pollution. A powerful and unnamed oil company kept a case in the lower court for 10 years. I did all the research work in the matter and gave testimony at the trial. After the case had been held in the lower court for 10 years it went to the Supreme Court and the decision of the lower court, which had thrown out the case on the ground of no cause for action, was reversed. The Supreme Court awarded damages and complete costs. The oil company still contested the action but finally gave up and paid the oyster-men involved $221,000 plus all costs.

REPORTS OF SESSIONAL COMMITTEES

COMMITTEE ON TIME AND PLACE

Seth Gordon

I am reporting for the Joint Committee on Time and Place of the two organizations, the International Association of Game, Fish and Conservation Commissioners, and the American Fisheries Society.

The Committee, after discussing the question of hotel facilities available in different parts of the country, and considering the invitations from the States of Oklahoma and Colorado, unanimously decided to accept the invitation of the State of Colorado, the meeting to be held in Denver the week of September 8 to 12. In accordance with the custom of the past the American Fisheries Society will meet first and the International meeting will follow unless the officers of the Executive Committee of the two organizations shall in the meantime find it desirable to reverse the order of the meeting.

It was felt that in 1948 the meeting should go to the eastern part of the country, and that in 1949 we should again return to Canada, probably the Prairie Provinces, as they have been asking for a number of years for these meetings.

AUDITING COMMITTEE

James R. Simon

We have examined the bank statements, vouchers, cash book, and bank books, and find them to be in agreement with the financial statement for the period July 1, 1945–June 30, 1946, as reported by the Secretary Treasurer.

The Auditing Committee also recommends approval of the following expenditure budget for 1946–47, as proposed by the Secretary-Treasurer:

Safe deposit	$ 4.80
Postage	100.00
Insurance	22.20
Clerical	
Hunter	100.00
Kane	400.00
Travel	
Kane	200.00
Officer travel to be authorized by Executive Committee	200.00
Indexing and other editorial expense	250.00
Printing	
Volume 73	2,200.00
Volume 74	2,200.00

Announcements	75.00
Membership solicitation Historical sketch	50.00
	$5,802.00

RESOLUTIONS COMMITTEE

Ralph Hile

1. Special Committee to Consider Increase of Dues

Whereas, The present financial reserves and the anticipated income of this Society obviously will prove inadequate to meet the operating costs of the organization and defray the expenses of printing the several volumes of the Transactions that should be issued within the next 2 or 3 years, now therefore

Be It Resolved, That the President of the Society is hereby directed to appoint a Special Committee of three members whose duty it shall be to consider the desirability of increasing the annual dues, and

Be It Further Resolved, That this Committee shall submit its recommendations to the Society at the next regular meeting.

2. Amendments to By-Laws

Whereas, The title, "Committee on Publications" fails to indicate properly the true function of that Committee, and

Whereas, The schedule of publication of the Transactions has been disrupted by the war and may suffer similar disruption at some further date; now therefore

Be It Resolved, That Article V of the Constitution and By-Laws of the American Fisheries Society be amended by substituting "Editorial" and "Editorial Board," respectively, for "Publications" and "Committee on Publications" in the first paragraph, and by rewording the fifth paragraph as follows:

> "The Editorial Board shall be composed of an Editor and four Associate Editors, and its duties shall be to select and edit manuscripts submitted for publication. The Editor shall have the authority to establish a deadline for the submittal of any material. Papers accepted by the Editorial Board, together with minutes of the regular and special meetings and reports of the various divisions and committees, shall be published in an annual volume which shall be numbered in series with previous volumes and entitled: Transactions of the American Fisheries Society.

3. Amendments to By-Laws

Whereas, The emergencies that forced the cancellation of the Society's regular meetings in 1942, 1943, 1944, and 1945 made impossible the annual election of officers and appointment of committees as provided by the Constitution and By-Laws, and

WHEREAS, Any action that was taken after September 18, 1942, by the officials of the Society, in order to assure the continuation of activities and the business administration of the organization, was of necessity not properly authorized under the Constitution and By-Laws, and

WHEREAS, The recurrence of conditions that may necessitate the cancellation of future regular meetings is within the range of possibility; now therefore

BE IT RESOLVED, That the American Fisheries Society at its Seventy-sixth Annual Meeting at St. Paul, Minnesota, on September 13, 1946, hereby gives its formal approval of the official actions of its officers over the 4-year period during which their exact status cannot be defined under the present Constitution and By-laws; and

BE IT FURTHER RESOLVED, That in order to assure the continuous and duly authorized administration of the Society's affairs in the event of the future cancellation of a meeting or meetings, the Constitution and By-Laws be amended as indicated beow:

> Article IV by the insertion of the following sentence immediately after the ordinal listing of the divisions: "'In the event of the cancellation of a regular meeting or meetings the officers listed above shall continue to hold their positions until such time as a regular meeting can be held and new officers elected."
>
> Article V by the addition of the following paragraph:
>
> "'In the event of the cancellation of a regular meeting or meetings the members of the several committees shall continue to serve, and the term of office of each member of the Committee on Publications shall be lengthened by the number of years in which no regular meetings are held."
>
> Article VI to read as follows:
>
> "The regular meeting of the Society shall be held once a year, the time and place to be decided upon at the preceding meeting, or, in default of such action, by the Executive Committee. Special meetings shall be called by the President upon approval of a majority of the Executive Committee. If circumstances demand such action, the Executive Committee by majority vote shall have the power to cancel the regular meeting and decide the time and place of the first meeting to be held thereafter.
>
> Should an issue of sufficiently great import to require action by the Society as a whole arise during the period following the cancellation of a regular meeting, the President, with the approval of a majority of the Executive Committee, may distribute an official ballot by mail to all members eligible to vote in regular annual meetings, and the results of this balloting, properly recorded and

certified by the Secretary, shall have equal status with the ballots cast at a reguar meeting."

4. *Revision of Constitution and By-laws*

WHEREAS, The documentation of the Constitution and By-Laws of the American Fisheries Society is eminently unsatisfactory in the following respects:

1. The Constitution and the By-laws are incorporated in a single instrument, and this instrument fails to indicate whether the individual articles or paragraphs pertain to the Constitution or to the By-Laws;
2. Article VIII specifies the procedure for changing the By-Laws but contains no provisions for the amendment of the Constitution; and
3. Numerous changes in the Constitution and By-Laws enacted by the Society in past regular meetings actually have never been incorporated in the printed document; now therefore

BE IT RESOLVED, That the President of the Society is hereby directed to appoint a Special Committee for the Revision of the Constitution and By-Laws to consist of three members whose duty it shall be to revise the present Constitution and By-Laws, preparing a separate Constitution and separate By-Laws; and

BE IT FURTHER RESOLVED, That the Committee shall include in the revision of the Constitution provision for its amendment similar to that now set forth in Article VIII for changes in the By-Laws; and

BE IT FURTHER RESOLVED, That the Committee shall examine at least the 15 most recent volumes of the TRANSACTIONS in order that it may ascertain the changes in the Constitution and By-Laws that have been enacted by the Society but not incorporated in the printed document, and incorporate them, as well as changes approved at the present meeting, in the above-mentioned revisions; and

BE IT FURTHER RESOLVED, That the Committee shall submit its revisions of the Constitution and By-Laws to the Society for its consideration at the next regular meeting.

5. *Committee on Standardization of Terminology and Procedures*

WHEREAS, The present great diversity in terminology and procedures creates considerable confusion in the interpretation of data and hampers the interchange of information among workers in fishery biology and fish culture; now therefore

BE IT RESOLVED, That the President of this Society is hereby directed to appoint a Special Committee of seven members, to be known as the Committee on Standardization of Terminology and Procedures, whose function it shall be to study questions of standardization and to submit to the Society recommendations as to uniformity in the expression of weights and measures, in the designation of ages of fish, in the measurement of the lengths of fish, in the classification of sizes of fish reared in fish-cultural establishments, and in such other matters of standardization as the Committee may see fit to consider; and

Be It Further Resolved, That this Committee shall submit its report to the Society at the next regular meeting.

6. Federal Aid to Fish Restoration and Management in the United States

Whereas, The demands of increasing millions of United States citizens who seek healthful outdoor recreation in angling are placing the fishery resources under constantly growing pressure, and

Whereas, The departments of fish and game of the various states are unable to meet adequately the increasing responsibility for fish restoration and management with the funds available to them from license fees or other sources and

Whereas, The Federal Aid to Wildlife Restoration Act, commonly known as the Pittman-Robertson Act, has proved to be a wise and effective measure for the conservation of mammals and birds, and

Whereas, A similar Act to aid in the restoration, preservation, and management of fish would be of vast benefit to the people of the United States; now therefore

Be It Resolved, That the American Fisheries Society, at its Seventy-sixth Annual Meeting, at St. Paul, Minnesota, on September 13, 1946, hereby reaffirms its previous resolutions and recommendations with respect to federal aid to fish conservation, and recommends urgently that the Congress of the United States enact such a similar bill but with the provision that the full amount of the tax collected in any one fiscal year be automatically available for the purpose of the act in the following fiscal year as in the case of the Duck Stamp Act, and

Be It Further Resolved, That the Secretary of the Society is hereby directed to transmit copies of this resolution to the Hon. S. O. Bland, Chairman of the Committee on the Merchant Marine and Fisheries of the House of Representatives, to Congressman A. Willis Robertson, and to the presiding officers of the Senate and the House of Representatives of the United States Congress.

7. Control of Pollution

Whereas, The American Fisheries Society in cooperation with other conservation agencies has repeatedly advocated the effective control of pollution, and

Whereas, It has been amply demonstrated that existing state and local authority alone is inadequate, now therefore

Be It Resolved, That the American Fisheries Society at its Seventy-sixth Annual Meeting, at St. Paul, Minnesota, on September 13, 1946, urges that the 80th Congress enact legislation similar to H.R. 6024, (otherwise known as the Mansfield Bill), of the 79th Congress, to bring about effective control of pollution on a national basis in cooperation with state and federal agencies concerned, and

Be It Further Resolved, That the Secretary of the Society is hereby directed to forward copies of this resolution to the President of the United States, the Chairman of the House Rivers and Harbors Committee, the Chairman of the Senate Commerce Committee, the Surgeon General, and to the ranking majority and minority members of the House and Senate.

8. Construction of Dams

Whereas, The Army Engineers Corps and the Bureau of Reclamation are developing large-scale, basin-wide projects for flood control, power, irrigation, and navigation in waters draining into the Pacific Ocean, and

Whereas, Many of the proposed developments may spell the doom of runs of anadromous salmon and steelhead trout, particularly in such streams as the Sacramento, Klamath, Rogue, and Columbia Rivers, and

Whereas, The Bonneville, Grand Coulee, and Shasta Dams have already materially reduced the runs of these fish in the Columbia and Sacramento Rivers and the construction of further major dams on or below the mouth of the Snake River, on the Columbia, or the Table Mountain Dam (Iron Canon) on the Sacramento will destroy future runs by blocking them from access to the only spawning grounds remaining accessible, now therefore

Be It Resolved, That the American Fisheries Society at its Seventy-sixth Annual Meeting, at St. Paul, Minnesota, on September 13, 1946, express its opposition to the construction of these dams mentioned or similar dams that will block access to spawning areas essential to the perpetuation of the species, and

Be It Further Resolved, That the Secretary of the Society is hereby directed to forward copies of this resolution to the President of the United States, the Secretary of War, the Secretary of the Interior, and the Chairmen of the Senate and House Appropriation Committees.

9. Facilities for Instruction and Training in Fish Culture

Whereas, Adequate facilities are now lacking for formal training in the principles and methods of modern fish culture, and

Whereas, The need for such facilities is great, particularly for the instruction of veterans eligible to receive technical training under the provisions of the "G. I. Bill of Rights," now therefore

Be It Resolved, That the American Fisheries Society recommend that, steps be taken to remedy this deficiency, and

Be It Further Resolved, That this Society suggest that the provision of such facilities may properly be a function of the United States Fish and Wildlife Service.

10. Donation of copies of the TRANSACTIONS *to the Philippine Bureau of Fisheries*

WHEREAS, Prior to the Japanese invasion of the Philippine Islands, the Philippine Bureau of Fisheries was one of the outstanding fishery research agencies of the Orient, and

WHEREAS, Its buildings, records, and library were destroyed by the enemy, and thus the Philippine Bureau of Fisheries is seriously handicapped in reestablishing its work, now therefore

BE IT RESOLVED, That, as a gesture of good will and as a contribution to the rehabilitation of the Philippine Islands, the American Fisheries Society donate to the Philippine Bureau of Fisheries one copy of each available back volume of the TRANSACTIONS, and that in transmitting these publications the Secretary be instructed to convey to the Director of the Philippine Bureau of Fisheries the felicitations of the Society and its hopes for early reestablishment of fishery research in the Philippines.

11. Great Lakes Fisheries Convention

WHEREAS, The fisheries of the Great Lakes are the principal source of fresh-water fish for the markets of the United States and Canada, and

WHEREAS, The productivity of these fisheries has declined substantially from its former maximum, with a consequent reduction in employment in the fisheries, a loss of income to the communities bordering on the Great Lakes, and a significant loss of food to the people of both countries, and

WHEREAS, The said decline and economic losses have been attributed primarily to the absence of adequate and uniform regulations of the fisheries, and

WHEREAS, All previous efforts to obtain informal cooperation in and coordination of the regulation and management of the Great Lakes fisheries have failed, thus demonstrating conclusively that the objective of adequate and uniform regulation of the fisheries is not attainable under the divided jurisdiction that presently obtains, and

WHEREAS, Concerted action on an international basis is the only practicable means of restoring, managing, and conserving the Great Lakes fisheries; now therefore

BE IT RESOLVED, That the American Fisheries Society, at its Seventy-sixth Annual Meeting at St. Paul, Minnesota, on September 13, 1946, hereby reaffirms its previous resolutions and recommendations with respect to the establishment of international administration for the Great Lakes fisheries, and recommends urgently that the Governments of the United States and of Canada ratify at the earliest possible date the "Convention for the Development, Protection and Conservation of the Great Lakes Fisheries," signed at Washington on April 2, 1946; and the Society further recommends the prompt enactment of appropriate implementing legislation by the Congress of the United States and the Parliament of Canada, and

Be It Further Resolved, That the Secretary of the Society is hereby directed to transmit copies of this resolution to the presiding officers of the Senate and the House of Representatives of the United States Congress, to the presiding officers of the Senate and the House of Commons of the Canadian Parliament, to the Secretary of State of the United States, to the Secretary of State for External Affairs of Canada, to the United States Secretary of the Interior, and to the Minister of Fisheries of Canada.

12. Appreciation of Hospitality

Whereas, This organization on the occasion of its Seventy-sixth Annual Meeting has been the recipient of unprecedented considerate and gracious hospitality, now therefore

Be It Resolved, That the American Fisheries Society hereby extends its heartfelt gratitude to the individuals and organizations who have worked so unstintingly to make our first post-war meeting such a memorable success, and

Be It Further Resolved, That the Society expresses its special appreciation to: Chester S. Wilson, Commissioner, Verne Joslin, Director of the Tourist Bureau, and other staff members of the Minnesota Department of Conservation; the Administration of the City of St. Paul; the St. Paul Association of Commerce; Ramsey County Sportsmen's Association.

COMMITTEE ON NOMINATIONS

Fred A. Westerman

The Committee on Nominations herewith submits its report. The Committee experienced some difficulty in giving appropriate representation to every section of the United States and Canada due to non-membership in some instances; in other cases, qualified members were ineligible because of failure to attend either this or the two preceeding meetings. No copy of the Transactions for the 1940 meeting was available. The Committee on Nominations proposes the following officers and committees to serve during the forthcoming year:

Officers

President	Joe Hogan, Arkansas
First Vice-President	H. H. MacKay, Ontario
Second Vice-President	Seth Gordon, Pennsylvania
Secretary-Treasurer	Russell P. Hunter, Connecticut
Librarian	Kenneth E. Cobb, Connecticut

VICE-PRESIDENTS OF DIVISIONS

Fish Culture	O. Lloyd Meehean, Illinois
Aquatic Biology and Physics	Edward Schneberger, Wisconsin
Commercial Fishing	Wm. J. K. Harkness, Ontario
Protection and Legislation	F. A. Westerman, Michigan
Angling	C. N. Feast, Colorado

COMMITTEE ON INTERNATIONAL RELATIONS

H. J. Deason, District of Columbia, *Chairman*
A. G. Huntsman, Ontario
Alan C. Taft, California
William C. Herrington, Massachusettts
J. A. Rodd, Ontario
G. W. Bennett, Illinois
Elliott S. Barker, New Mexico

COMMITTEE ON STATE AND NATIONAL RELATIONS

C. R. Gutermuth, District of Columbia, *Chairman*
A. D. Aldrich, Oklahoma
C. F. Culler, Minnesota
Stillman Wright, Utah
Lloyd L. Smith, Jr., Minnesota

COMMITTEE ON COMMON AND SCIENTIFIC NAMES OF FISHES

Walter H. Chute, Illinois, *Chairman*
W. A. Clemens, British Columbia
John R. Dymond, Ontario
Samuel F. Hildebrand, District of Columbia
George S. Myers, California
Leonard P. Schultz, District of Columbia
Reeve M. Bailey, Michigan

COMMITTEE ON POLLUTION

Kenneth A. Reid, Illinois, *Chairman*
Carl D. Shoemaker, District of Columbia, *Secretary*
Seth Gordon, Pennsylvania
Emmeline Moore, New York
J. A. Rodd, Ontario
George B. Eusterman, Minnesota
Alan C. Taft, California
T. H. Langlois, Ohio
Marion Toole, Texas

MR. WESTERMAN: Mr. President, I offer for your consideration this list of candidates for office, and for the various standing committees, and recommend its adoption.

Mr. Denmead: I move that nominations be closed, and that the Secretary cast a ballot for the persons named.
[Motion carried unanimously.]

The Retiring President: I will ask Dr. Raymond Johnson and Mr. George Sprecher to escort the new President to the rostrum—Mr. Joe Hogan.
[And the Presdent-elect having been escorted to the chair]:

The Retiring President: Mr. Hogan, I wish to congratulate you and wish you all the success in the world. I hope we have as good a meeting in Denver as we have had here.

CONCLUDING BUSINESS

THE PRESIDENT-ELECT: Thank you, Dr. Van Oosten. I appreciate the high honor which has been conferred upon me in being elected President of this Society. I am certain there are many in the audience here who are much more qualified than I. But being somewhat of a democrat I believe the strength of an organization is more in the body of it than in the head; so I expect you to work with me in the coming year. I trust that our meeting in Denver will be a big success.
Is there any further business to come before the meeting?

MR. GOTTSCHALK: I move that the President of the Society appoint a special committee to examine the possibility of changing the form of publication of the TRANSACTIONS of the Society from that of an annual volume to that of a quarterly journal, four numbers of which would constitute an annual volume; that this special committee be directed to determine the practical difficulties of editing, publishing, and financing such quarterly journal; and that this committee report its findings and conclusions to the Society at the next annual meeting. [The motion carried.]

MR. DENMEAD: It has been the custom of this Society to elect a President for one year only. Dr. Van Oosten, our retiring President, has been at the head of this Society for 5 years. It is only fair that we should tell him we have appreciated his services, congratulate him on his success, and wish him well in the future.

MR. SIMON: I should like to second that motion. [The motion carried.]

MR. WESTERMAN: I want to endorse what Mr. Denmead has just said and to add an expression of my appreciation of the hard work Dr. Van Oosten has done in the interests of the Society during the 5 years he has been its presiding officer. I am sure we all appreciate it.

THE PRESIDENT-ELECT: We can all join very heartily in that expression of appreciation. Is there any further business?

DR. NEEDHAM: There is one matter I would like to mention. We who live on the West Coast have difficulty in attending these meetings more than once every 5 or 6 years. If we had a western section or western division, it would give us a chance to meet oftener, and I do not think such a division would decrease the attendance at the national meetings. We feel that the dues should be paid to the national body, not to the western division. Since coming to this meeting it has occurred to me that the best way to treat this problem would be to move that a committee be appointed to study the matter and to make its recommendations at the next annual meeting. If it is in order, I so move.

DR. DEASON: I believe that the membership of this Society from the West Coast is not at all indicative of the men engaged in fishery work in that region, and their remoteness of contact has probably been responsible for their lack of attendance at the meetings. I therefore am very happy to second Dr. Needham's motion that a committee be appointed to study the matter and report at the next meeting.

DR. NEEDHAM: It is true we have over 100 workers, but they are concerned principally with marine species. Probably 30 or 40 of them are concerned with freshwater forms. It would be a great advantage to the fishery men on the west coast if they could have the chance to meet once a year under the auspices of the American Fisheries Society; that meeting might be combined with the Western Association meeting, just as the main body of the American Fisheries Society joins annually with the main body of the International Association of Game, Fish and Conservation Commissioners.

[The motion carried.]

DR. VAN OOSTEN: I move that we adjourn.

[The motion was seconded by Mr. Reid and carried.]

The Seventy-sixth Meeting of the American Fisheries Society was adjourned to meet in Denver, Colorado, the week of September 8, 1947.

Appendices

INSTRUCTIONS FOR PREPARING MANUSCRIPTS FOR THE TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY

(REVISED 1946)

Please check each item below before the final typing of your manuscript and help your Society reduce the costs of publication, save your Editorial Board (which works gratis) much needless work, time, and expense, and avoid delay in the publication of the *Transactions.*

The following instructions were not drawn up arbitrarily but were condensed from the regulations contained in the best style manuals (Government Printing Office Style Manual; University of Chicago Style Manual). Certain instructions may appear unnecessary, but they are nevertheless essential for the proper handling of materials by the printer and the editor.

I. MECHANICAL DETAILS

1. **Manuscript must be typewritten double-spaced,** including titles, headings, legends for tables and illustrations, and literature citations. Use one side only of sheet. Do not fold manuscript. Write manuscript only in simple upper and lower case. *Do not use all capital letters for any purpose and underscore only when italics are intended.*

2. **Carbon copies will not be accepted.** Do not use thin, transparent paper. Heavy bond paper is preferred.

3. **Margins** at top, bottom, and both sides must be no less than 1¼ inches to allow space for the insertion of directions to the printer and necessary corrections.

4. **Pages** must be numbered in consecutive order, including the literature cited, tables, charts, and photographs. Tables and legends of charts and illustrations must be inserted near their place of reference in the text.

5. **Illustrations.** Make separate pages of tables with headings (not of leader work), of legends, of diagrams, charts, and illustrations, and limit the number to those absolutely necessary to clarify or supplement text. *Tables and cuts cost money!* Only sharp, glossy photos can be used. All drawings, charts, and diagrams should be prepared in waterproof India ink on Bristol Board, other perfectly smooth white paper or cardboard, or tracing cloth. Graph paper must not be used. No erasures should be made. Shading should be limited to a minimum and when used the shading lines should be kept open. The curves of graphs should be drawn much bolder than any guide lines or ruling. Lettering should be bold and sufficiently large and spaced apart so that the letters or numbers will not be less than 1 millimeter high or come in contact when reduced. Drawings should be made at least twice the size required for reproduction, and when large should be of proper proportion so that they will not exceed 4¼ by 6½ inches (inclusive of legends) when reduced. All explanatory matter other than the units along each axis of a graph or diagram and those designations needed for clarity should be placed in the legend. The legend, which should be typewritten on a separate sheet, will be set in type below the figure.

Make proper reference in text to all plates, figures, maps, charts, and tables, and designate all of these, except tables, as figures, numbering them in consecutive order with Arabic, not Roman, numerals.

6. **Footnotes** in text should be numbered consecutively and should be placed immediately after the full line of text in which the reference mark occurs, but do not break a line of text to insert footnote. Separate the footnote from the text by two horizontal lines, one above and one below the note. In each new table footnotes should begin with 1.

7. **The title** of the manuscript, together with the author's name (write out in full either one or both of the Christian names and do not use "by"), position or department, and post office address, should always appear at the top of the first page of the manuscript as follows, allowing at least *triple space between lines* to permit the insertion of instructions to the printer.

REPORT ON THE DISEASES OF BROOK TROUT
JOHN EDWARD DOE
Department of Conseration, Lansing, Michigan

8. **Underscore** (italics) all scientific names of genera and species, both animals and plants, in both text and tables. Do not underscore or use all capital letters for scientific names of a category higher than the genus: Esocidae; *Esox lucius. Do not underscore any words unless italics are intended.*

9. Inspect papers in the last volume of the *Transactions* if you have questions concerning the arrangement of materials.

II. STYLE

10.. **Bibliographic references** in text should give name of author and year of publication in parenthesis, thus (Doe, 1932). Do not use letters or numbers or footnotes for references. If more than one publication by the same author is given for a year, use the alphabet to designate the correct paper, thus (Doe, 1932a) or (Doe, 1932b). In the bibliography do not repeat the author's name if reference is made to more than one of his publications, but list his publications in chronological order beginning with the earliest one. In citing a joint publication invert the name of the senior author but not of the co-author or co-authors. *Do not include any reference not mentioned in the text.* List authors in alphabetical sequence. Capitalize the first word and proper names only in the title. Follow the arrangement given below to be placed at end of paper:

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Please check your references carefully as to titles, spelling, capitalization, italics, diacritical marks, abbreviations, etc., against their original sources, after the final typing, and *state beneath your bibliography that you have done so.* Many bibliographic titles published in the *Transactions* have been found to be incomplete and very inaccurate. Help us correct this situation.

11. **Tables.** Every table should have a heading and must be typewritten on a separate page. Insert tables among the text pages near the points where they are discussed. In preparing tables please be certain that they are not too large to appear on a single printed page. Number tables consecutively with Arabic, not Roman, numerals (1, 2, 3, etc.). Abbreviate the word "number" (No.) when referring to a special number—not when referring to quantity or things. Spell all other words in

Item	Number of fish	Percentage of total	Average length in millimeters	Months	Cost of diet per pound
Brook trout surviving experiment No. 2	23	5.8	6.5	April-September	$0.25

tables, including such words as "millimeters," "ounces," and "average" (except months *with date,* in body of table), and capitalize, as a rule, the first word only in headings in the first column or over other columns. Precede all decimal numbers with zero. Use dollar sign only with first number at top of column and under each cross rule.

12. **Capitals.** Capitalize words when used as part of a proper name or of an identifying number or letter, or when referring to a particular State, Government, and to organized bodies, or when used as proper names. For example: Lake Michigan, State of Michigan, or the State, the Province, the Republic, or the National and State Governments, Washtenaw County, Ann Arbor Township, Huron River, Pacific Ocean, North Atlantic, Northern States, Reservoir No. 1, Hoover Dam, Pond No. 1 or Pond A, State Fish Farm No. 1, Pisgah National Forest, American Fisheries Society.

Capitalize names of sections of the United States, or of any other country, as Middle West, but use lower case for a term prefixed to any such sections, as eastern North Atlantic States.

Capitalize any term (except page or pages and age group) preceding Roman numerals, as Article I, Chapter II, Sample VI, etc . Also capitalize such terms as Appendix 1 or Appendix A, Experiment 2, Table 4, and Figure 8 (referring to illustrations).

Use lower case for scientific and common names of species. Capitalize scientific names of higher categories.

13. **Abbreviations.**

(a) Abbreviate the following:

Clock time, if connected with figures—2:30 a.m.

Temperatures—F. (Fahrenheit).

Degrees, whether referring to temperatures, longitude and latitude, or angles, etc.—75°, 75° F., 75° C.

"Number," if preceding figures—No. 125; otherwise spell out.

"United States," if preceding name of a department or a bureau of a vessel, etc.—U. S. Department of the Interior, U. S. S. *Indiana.*

Months, in body of tables and footnotes to same when followed by day of month—Apr. 5-Sept. 2 (but April-September).

(b) Do not abbreviate the following:

States, cities, etc.

Months, in text or in headings of tables—April 5-September 2.

Measures and weight, except p.p.m.—6 inches, 20 millimeters, 5 ounces, 1.5 acres, etc.

Percentage—12 percent, a percentage of 25.5.

14. **Numerals.** Spell out all *isolated* numbers less than 10, but use figures in a group of enumerations when any one number of that group is 10 or greater. Do not spell out numbers of two or more digits (except round numbers of approximations: estimated at five hundred; a thousand fish), and always use a comma in a number of four or more digits. Treat alike all numbers in a series of connected groups. For example: There were nine trout. There were 9 trout, 120 bass, and 50 pike.

Use figures for all enumerations of quantities and measurements, such as dimension, weight, area, volume, distance, clock time, time, money, percentage, degrees, proportion or ratios, ages, dates, page numbers, decimals, and mixed numbers (spell out common fractions if alone: one-eighth inch). For example: $3.00 per 20 pounds; 5 feet 6 inches; 10 miles; 6 acres; 15 cubic centimeters; 4:30 p.m.; fish died in 1 hour and 20 minutes; 25.5 percent; 75° F.; 1:10,000; trout 2 years 6 months old; 2-year-old trout; June 29, 1936; the 1st of January, 1938; the 20th day of March; 1937-38; 4.5 p.p.m.; 0.25; 1½ pages; page 215.

Write 8 by 12, not 8 x 12 unless multiplication is indicated. Write 50-50, not "fifty-fifty."

Do not use two figures when two numbers appear together, unless the first enumeration exceeds 100: ten 12-room houses; twenty 6-inch trout; 120 6-inch trout.

Spell out figures beginning a sentence, but avoid such use of numerals if possible. Spell out both numbers of two related amounts at the beginning of a sentence in such expressions as "Twenty to twenty-five trout," but write "Two hundred fifty bass and 325 trout were shipped."

Spell out such indefinite expressions as the following: Between two and three hundred fish; there were thirty or forty thousand trout.

In expressing large numbers the word *million* (or a similar larger group term) may be spelled out: 20 million, 2¾ billions.

15. **Use of hyphen.** Many compound words when used as nouns are not hyphenated but require the hyphen when used as adjectives. For example note the following sentences: "This species is adapted to *cold-water.*" "Trout are *cold-water* fish." Write "fish culture," but "fish-culturist." Check your manuscript carefully for use of hyphen. The words, "subspecies," "upstream" and many other words originally of compound derivation are written without a hyphen.

Write "largemouth" and "smallmouth" as one word when referring to black bass.

III SUBJECT MATTER

16. **Condense your paper** to the limit and omit all needless verbiage to reduce cost of printing. The manuscript should be simple, clear, concise, accurate, consistent, and complete. *Accuracy* in subject matter, in scientific names, and in bibliography is especially important. Have your associates read and criticize your paper before the final typing. **Papers which are too poorly written will be rejected.**

17. **Be definite in references to species.** The scientific name, and wherever needed the *complete* common name, that will identify the species about which the paper is written should be included in the title as well as in the text, unless the number of species is too large. Such names as "bass," "trout," and "pickerel" apply to any one of several species. Do not write "smallmouth," "brook," "rainbow," etc., when you mean "smallmouth black bass," "brook trout," "rainbow trout," etc.

18. **Things to avoid.** Words that do not appear in the dictionary in the sense employed should be avoided. The *words* "case," "instance," "show," "found," "gave," and "present" are greatly overworked in manuscripts.

Avoid the repeated use of *participles* which, as a rule, weaken sentences. In the following illustration note the improvement when the words in parentheses are used: "The principles underlying (that underlie) the production of beef are essentially the same as those involving (that are involved in) the production of bass."

Avoid *split infinitives.* Please check your manuscript for this exceedingly common error.

Avoid the use of *this* and *these* as substantives. Compare, for example, the following two sentences for effectiveness: "*This* was true in every case." *"The mortality* was *high* in every *pond."*

Avoid the use of a long series of nouns and adjectives as modifiers.

19. **Abstract of paper.** Give a condensed summary or brief abstract at the beginning of your paper.

Prepared by the Editorial Board
February, 1937 (revised 1946)

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INDEX TO VOLUME 76

A

Abundance, analysis of, 291-293
  lake trout, 135-139, 143-146
  longjaw cisco, 219-223
Acarina, 112
Acilius sp. 113
Adams, William C., 3; (in memoriam), 8
Aeschnidae, 111, 113
Aeschna umbrosa, 109
Age and growth, longjaw cisco, 215-247
Algae, 305-308, 312
Alkalinity, relation to productivity, 324-325
Ambloplites rupestris, 64-65, 74-75, 166-167, 304
Ameiuridae, 111-112
Ameiurus melas, 27-30, 32, 208
  natalis, 27-30, 32
  nebulosus, 27-30, 32, 304
Amia calva, 27, 166-167
Amnicola, 308
Amphibia
  Rana, 111-114
Amphiagrion saucium, 310
Anabaena, 350
Anacharis, 345
  canadensis, 303
Analysis, creel-census data, 290-300
  feeding habits, trout, 301-314
Anax junius, 109, 112-114
Anisoptera, 109, 111-114
Annelida
  Hirudinea, 312
Aquatic plants, control, 183-189
Aphidae, 109, 112
Arachnida
  Acarina, 112
  Hydracarina, 312
Arctocorisa sp., 310, 312
Atherix, 257
Availability, phosphorus, 348
Aves
  Megaceryle a. alcyon, 97-117
Azotobacter, 349-351

B

Back Creek, West Virginia, toxicity of DDT to fish, 315-321
Bacteria
  Azotobacter, 349-351
  Bacterium salmonicida, 83, 88-89, 93-94
  Lactobacillus casei, 35
Baetinae, 109, 310
Bailey, Reeve M., 4
Banksiola selina, 310
Barker, E. S. (disc.), 378-379
Bass, 19, 105, 110
  largemouth, 27, 301, 304, 309
    DDT treatment, 316, 320-321
    management, relation to weed control, 178-179
    pond experiments, 46-62
    rate of growth, 65, 78-79
    sex ratio, 78
  rock, 166-167, 304
    rate of growth, 64-65, 74-75
    sex ratio, 74
  smallmouth, 165-166, 301, 304
    DDT treatment, 315-316, 318-320
    rate of growth, 65, 80-81
    sex ratio, 80
Beckman, William C., 63-81
Belmont, Perry (in memoriam), 8
Belostomatidae, 109, 112-114
Belastoma flumineum, 310
Benacus sp., 113
Berosus, 111
Birch Lake, Michigan, feeding habits of trout, 301-314
Bloater, 237
Bluegill, 27-30
  DDT treatment, 317-321
  forage fish, 48, 50-51, 54, 58-61
  management, relation to weed control, 178-179
  oxygen threshold, 32
  pond experiments, 46-62
  rate of growth, 65, 68-69
  sex ratio, 68
  survival and growth, 190-203
Boleosoma nigrum, 111, 208-209
Bottom soil, fertilization, 339-342
Bowfin, 27
Brachycentrus sp., 310
Buller, Nathan R. (in memorium), 8
Bullhead, 166-167
  black, 27-30, 32
  brown, 27-30, 32, 304
    DDT treatment, 318-319
  yellow, 27-30, 32
Bulrush, 187
Business session, 391-444
  committees, reports, 404-442
  officers, reports, 395-400
  secretary-treasurer, 395-398
  vice-president, fish culture, 398-400
Butler, (disc.), 417
Bythinia, 308

C

Callibaetis sp., 310
Cambarus, 101, 109-114, 308
  diogenes, 112
  immunis, 109-110, 113-114
  propinquus, 109, 112-114
  virilis, 109-110, 112-114
Camponotus herculeanus, 111
Campostoma anomalum pullum, 208-209
Carabidae, 109
Carassius auratus, 55-58, 61-62
Carbon, relation to nitrogen fertilization, 351-352
  bisulfide, weed control, 181
  dioxide, free, relation to productvity, 325
  tetrachloride, weed control, 181
Carex, 342
Carlander, K. D. (disc.), 417
Carp, 111, 173-174, 341, 353
  culture in Europe, 336-339

Catch, analysis, 291-293
  lake trout, 136-139, 143-146
Catfish, 111
Catonotus flabellaris lineolatus, 208
Catostomidae, 109-110, 112-114
Catostomus commersonnii, 109-113, 165-166, 206-207, 209-211, 304, 316, 318-320
Cattail, 187
Census, creel, 269-274
  analysis of data, 290-300
Ceratophyllum, 187, 345
  demersum, 303
Ceratopogonidae, 310
Centrarchidae, 109-110, 309, 312, 314
Clemens, W. A., 4
Chaenobryttus coronarius, 27
Chaoborus punctipennis, 310
Chara, 249, 303
Chilodon, 18
Chironomidae, 109-110, 113, 257, 310, 312
Chironomus, 342
  lobiferus, 310
  modestus, 310
  plumosus, 310
Chlorides, relation to productivity, 326
Chrosomus eos, 250
  erythrogaster, 209
Chrysomelidae, 109, 111
Chub, creek, 166-167, 208, 259, 304, 309
  Reighard's, 237
Chubsucker, lake, 27
  oxygen threshold, 32
Chute, Walter H., 4, 419-421
Cicadellidae, 112
Cisco, 302, 304
  disappearance, 122-123
  longjaw
    abundance, 219-223
    age composition, 223-229
    age growth, and distribution, 215-247
    coefficient of condition, 238-243
    conversion, standard length to total length, 241
    distribution, 219-223
    growth, 229-238
    growth compensation, 237
    length frequencies, 223-229
    length-weight relationship, 238-243
    sex ratio and maturity, 243-245
    spawning season, 246
Cladocera, 305-308
Clark, Arthur L., 4
Clark, O. H., 248-278
Clinostomus elongatus, 208
Cobb, Eben W. (in memoriam), 8
Cobb, Kenneth E., 3
Coefficient of condition, longjaw cisco, 238-243
Coleoptera, 109-110, 112-113
  Acilius, 113
  Berosus, 111
  Donacia, 310
  Dytiscus, 109, 112-113
    dauricus, 112
    harrisii, 112-113
  Haliplus, 111-112, 310
  Hydrous triangularis, 111
  Phyllophaga, 312
Committees, appointment of sessional, 394
  list of members, 4-5
  reports of, sessional, 433-442
    auditing, 433-434
    nominations, 440-442
    resolutions, 434-440
    time and place, 433
  special, 425-432
    pollution, 425-432
  standing, 404-424
    common and scientific names, 419-421
    international relations, 404-417
    publications, 421-424
    state and national relations, 417-419
Conservation, by education, 118-120
  Missouri River development, 382-383, 387-388
Conversion, standard length to total length, longjaw cisco, 241
Coontail, 187
Cooper, Gerald P., 23-33
Copepoda, 305-308
Copper sulphate, weed control, 178
Coregonus clupeaformis, 122, 150
Costiasis, 16
Cottam, Clarence, 379-388
Cottus, 109-114, 309, 312
  bairdii, 113, 208, 304, 309
  cognatus, 112, 208-210, 250
Crappie, black, 27
  management, relation to weed control, 178
  oxygen threshold, 32
  rate of growth, 65, 76-77
  sex ratio, 76
Crayfish, 109-111, 258-259, 305-308
Cristivomer namaycush, 121-147, 150, 301-314
Crustacea
  Cambarus, 101, 109-114, 308
    diogenes, 112
    immunis, 109-110, 113-114
    propinquus, 109, 112-114
    virilis, 109-110, 112-114
  Gammarus fasciatus, 308
  Hyalella, 257
    knickerbockeri, 308
Culex sp., 310
Curculionidae, 111
Cyprinidae, 109-114, 309, 312
Cyprinus carpio, 111, 114, 166-167, 209

D

Dace, longnose, 208
  northern redbelly, 250, 259
Darter, fantail, DDT treatment, 318
  Iowa, 27, 195, 197, 304
    oxygen threshold, 32
  least, 304
DDT, relative toxicity of formulations to fish, 315-321
Dean, Herbert D. (in memoriam), 8
Deason, H. J. (disc.), 417; 421-424, (disc.), 443
Deflectors, angling changes due to, 268-275
  cost, 250
  effects on trout stream, 248-278
  results of installation, 254-268
Denmead, T. (disc.), 403, 442-443
Depletion, definition of, 283-289
Diptera, 109, 112
  Atherix, 257
  Chaoborus punctipennis, 310
  Chironomus, 342
    lobiferus, 310

    modestus, 310
    plumosus, 310
  Culex sp., 310
  Polypedilum nubeculosum, 310
  Simulium venustum, 310-311
  Tanypus stellatus, 310
  Tanytarsus jucundus dimorphus, 310
  Tipula abdominalis, 310
Disease, trout, 16-18
Distribution, longjaw cisco, 215-247
Dogfish, 166-167
Donacia sp., 310
Dorosoma cepedianum, 47-48, 53-55, 61
Dryopidae, 310
Dymond, John R., 4
Dytiscidae, 310
Dytiscus, 109, 112-113
  dauricus, 112
  harrisii, 112-113

E

Education, fishery conservation, 118-120
Eicher, George J., Jr., 13-22, 177-182
Elateridae, 111
Electric shocker, use in Michigan streams, 253-254
  use in population sampling, 205-206
Enallagma, 310, 312
Entomostracans, 305-308
Entosphenus, 208
  lamottenii, 148, 165
Ephemeridae, 109-110, 113
Ephemeroptera
  Callibaetis sp., 310
  Ephemera simulans, 310-311, 313
  Ephemerella temporalis, 310
  Hexagenia, 313
    limbata occulta, 310-312
Epiaeschna sp., 112
Epicordulia princeps, 310
Erimyzon oblongus, 316, 318-319
  sucetta, 27-30, 32
Eschmeyer, R. W., 3
Esox, 337
  lucius, 27, 29-30, 32, 112-113, 165-166
  niger, 316, 320
  vermiculatus, 27, 29, 32, 113, 304
Etheostomatinae, 109, 112-114
Eucalia inconstans, 109-110, 112, 114, 250
Europe, pond fertilization, 335-358
Evans, T. R. (disc.), 369
Exoglossum maxillingua, 111
Extermination, 287-288

F

Fallfish, DDT treatment, 316-319
Feast, C. N., 4; (disc.), 370
Feeding habits, trout, 301-314
Fertilization, control of aquatic plants, 183-189
  pond, central Europe, 335-358
    research, 352-354
Fin rot, 16
Fish culture, report of division, 398-400
Fish stocks, definition of depletion, 283-289
Fish and game, relation to flood control, etc., symposium, 359-388
Fishery, lake trout, 139-146
  programs, trends, 13-22
  survey, Upper Mississippi River, 279-282
Flood control, relation to fish and game, symposium, 359-388
  Act, 362-363, 366
Flounder, 111
Folger, J. A. (in memoriam), 8
Formicidae, 109
Fortmann, Henry F. (in memoriam), 8
Foster, Frederick J. (in memoriam), 8
Foster, George M. (in memoriam), 8
Friddle, Dorothy D., 315-321
Frogs, 109, 111
Fundulus diaphanus menona, 109-113, 304, 309, 312
  notatus, 27
Funk, J. (disc.), 431
Furunculosis, 16
  treatment, brook trout, 82-96

G

Gambusia affinis, 60-62
Gammarus fasciatus, 308
Gar, longnose, 304, 309
Goldfish, forage fish, 55-58, 61-62
Gordon, Seth, 5, 401-403; (disc.), 431-432; 433
Gottschalk, John, 4, 417-419; (disc.), 443
Gowanloch, J. N. (disc.), 378, 417, 432
Grayling, 16
Great Lakes fishery, effects of lamprey, 167, 172-174
Griffiths, Francis P., 5
Growth, bass, largemouth, 65, 78-79
    rock, 64-65, 74-75
    smallmouth, 65, 80-81
  bluegill, 65, 68-69, 190-203
  cisco, longjaw, 215-247
  crappie, black, 65, 76-77
  perch, yellow, 64-65, 70-71
  pumpkinseed, 65, 72-73
Growth and survival, bluegill fry, 190-203
Gutsell, James S., 82-96
Gyrinidae, 112, 310
Gyrodactylus, 16-18

H

Haliplus, 111-112, 310
Hatchery, kingfisher predation, 105-109
  loss by disease, 16-18
  trout, statistics, 14-18
Hazzard, Albert S., 5, 248-278
Helicopsyche, 109
Helisoma, 308
Hemiptera
  Arctocorisa sp., 310, 312
  Belostoma flumineum, 310
  Benacus sp., 113
  Lethocerus americanus, 109, 113
  Notonecta undulata, 310
Herrington, William C., 4, 404-417
Hexagenia, 313
  limbata occulta, 310-312
Higgins, E. (disc.), 424
Hildebrand, Samuel F., 4
Hile, Ralph, 4, 121-147, 434-440
Hiner, Laurence, 204-215
Hirudinea, 312
Hoffmaster, (disc.), 361, 368, 372, 378-379, 388
Hogan, Joe, 3, 183-189
Hubbs, Carl L., 4

Hunter, Russell P., 3, 395-398
Huntsman, A G., 4
Hyalella, 257
  knickerbockeri, 308
Hybognathus, 111
Hybopsis, 111
Hyborhynchus notatus, 109, 112-114, 209, 250, 304, 309, 312, 316, 318
Hydracarina, 312
Hydrocotyle umbellata, 303
Hydrodictyon, 187
Hydrogen-ion concentration, relation to productivity, 325
Hydrophilidae, 310
Hydroptilidae, 310
Hydrous triangularis, 111
Hymenoptera, 109, 111
  Camponotus herculeanus, 111
Hypentelium nigricans, 208, 315, 318-320

I

Ichthyomyzon fossor, 148-149, 165-166
  unicuspis, 148-149, 165-166
Insects, *see scientific name*
International relations, report of committee, 404-417
Iron, relation to productivity, 330
Irrigation, relation to fish and game, symposium, 359-388
Isogenus, 257
Isoperla sp., 310-311

J

Jackson, Charles E., 4
Johnson, Raymond E., 204-215

K

Kaupanger, (disc.), 369
Kendall, (disc.), 370
Killifish, 111
  western banded, 304, 309, 312
Kingfisher, distribution, 98-99
  feeding habits, 100-103
  food, 104-115
  mating and nesting, 97-100
  predation, 103, 115
  relation to fish management, 97-117
Kiyi, 223, 237
Kruger, H. (disc.), 432
Krumholz, Louis A., 190-203

L

Labidesthes sicculus, 27, 114, 304
Lactobacillus casei, 35
Lagler, Karl F., 97-117
Lake, Huron, lake trout fishery, 121-147
  productivity, indices, 322-334
  size, relation to productivity, 331-332
Lamprey, brook, American, 148, 165
    Michigan, 148-149, 165-166
  sea, control, experiments, 154-158, 164-170
    recommendations, 158, 175
    distribution in Michigan, 171
    effect on Great Lakes fishery, 167, 172-174
    investigations on, 148-159
    occurrence on fish, 152-154
    spread, 123
    status, future, 174-175
  silver, 148-149, 165-166
LeCompte, E. Lee (in memoriam), 8
Lepisosteus osseus oxyurus, 304, 309
Leonard, Justin W., 4, 301-314
Leonard, F. A., 301-314
Lepomis cyanellus, 109, 112-114, 193-195, 197, 208, 304, 309, 312
  gibbosus, 27-30, 32, 65, 72-73, 109-111, 114, 304, 309, 312
  megalotis, 202
  macrochirus, 27-30, 32, 46-62, 65, 68-69, 109-110, 112-114, 178-179, 190-203, 304, 309, 312, 317-321
Leptocella albida, 310
  exquisita, 310
Lethocerus americanus, 109, 112-113
Leucichthys alpenae, 215-247
  artedi, 122, 302, 304
  hoyi, 237
  kiyi, 223, 237
  reighardi, 237
  zenithicus, 237
Leucosomus corporalis, 111, 316-319
Libellula, 109, 310
License, statistics, 21
Lime, pond fertilizer, 342-344
Limnephilidae, 310
Locke, S. B., 5
Logperch, 304
Longjaw, Lake Superior, 237
Lonoke Hatchery, Arkansas, control of aquatic plants, 183-189
Lota lota maculosa, 114
Lotus, 184
Low, Ethelbert (in memoriam), 8
Lowe, (disc.), 370-371
Lymnaea, 308

M

MacGillivray, Earl, 148-159
MacKay, H. H., 3, 148-159
Madtom, tadpole, 27, 304
Manganese, relation to productivity, 330
Mailliard, Joseph (in memoriam), 8
Management, fish in relation to kingfisher, 97-117
  pondfish, statistics, 19-20
  trout, statistics, 14-18
  weed control, 177-182
Manuscripts, instructions for preparation, 447-450
Margariscus margarita nachtriebi, 109, 210
Marked fish, recovery, 265-273
Maurek, B. (disc.), 368-369
McCormac, Fred J., 4
Megaceryle a. alcyon, 97-117
Members, list of, 451-466
Menhaden, 111
Michigan, lakes, winter mortality, 23-33
  fishes, growth and sex ratio, 63-81
  trout streams, effects of deflectors, 248-278
  waters, sea lamprey problem, 160-176
Minnesota, trout streams, 204-215
Minnow, 105
  blackhead, DDT treatment, 317, 320-321
  bluntnose, 250, 259, 304-309, 312, 316, 318
    DDT treatment, 316, 318

fathead, 250, 259
forage experiments, 46-62
silverling, DDT treatment, 316-319
Microperca m. microperca, 304
Micropterus dolomieu, 65, 80-81, 110, 114, 165-166, 304, 315-316, 318-320
salmoides, 27, 46-62, 65, 78-79, 110-111, 178-179, 304, 309, 316, 320-321
Mississippi River, cooperative fishery survey, 279-282
Missouri River basin, symposium, 359-388
Mollusca
Amnicola, 308
Bythinia, 308
Helisoma, 308
Lymnaea, 308
Paludestrina, 308
Physa, 308
Pisidium, 308
Planorbis, 308
Pyrgulopsis, 308
Valvata, 308
Monochlorbenzene, weed control, 179
Moore, Emmeline, 5
Mortality, trout, furunculosis treatment, 84-86, 88-91, 93-96
winter, Michigan lakes, 23-33
Morton, W. P. (in memoriam), 8
Mottley, C. M., 4, 290-300
Moxostoma, 101, 112
aureolum, 165-166
Moyle, John B., 322-334
Muddler, 105, 250, 258-259, 304, 309
Mudminnow, 27-29, 105, 250, 259, 304
Myers, George S., 4
Myriophyllum, 180-181, 345
spicatum, 303
Mystacides sepulchralis, 310

N

Najas flexilis, 303
Natrix s. sipedon, 167
Natural fluctuation, 284, 287
Navigation, relation to fish and game, symposium, 359-388
Needham, P. R. (disc.), 443-444
Neess, John C., 335-358
Nelumbo, 187
lutea, 184
Neogomphoides obscura, 310
Neuroptera
Sialis infumata, 310, 312
Nitrogen, pond fertilizer, 348-352
relation to productivity, 328-329
utilization cycle, 349
Nocomis biguttatus, 208
Nostoc, 350
Notemigonus crysoleucas, 27-30, 32, 47-53, 61, 109-110, 113-114, 304, 312
Notonecta undulata, 310
Notropis, 111, 312
amoenus, 316-319
atherinoides, 113
cornutus, 109-113, 165-166, 208-209, 304-309, 312
dorsalis, 208
heterodon, 27, 32, 304, 309, 312
heterolepis, 27, 32, 250, 304, 309
hudsonius, 113-114
spilopterus, 208, 316-319
umbratilis cyanocephalus, 208
volucellus, 304, 308-309, 312
Noturus flavus, 208
Nuphar advenum, 303
Nymphaea odorata, 303

O

Octomitus, 16, 18
salmonis, 94, 96
Odonata, 109-110, 112
Aeschna umbrosa, 109
Amphiagrion saucium, 310
Anax junius, 109, 112-114
Enallagma, 310, 312
Epiaeschna sp., 112
Epicordulia princeps, 310
Libellula sp., 109, 310
Neogomphoides obscura, 310
Plathemis lydia, 310
Stylurus sp., 310
Tetragoneuria simulans, 310
Oecetis eddlestoni, 310
Officers, list of, 3
Ontario, sea lamphrey investigation, 148-159
Orthodichlorbenzene, weed control, 179
Orthoptera, 109, 112
Osmerus mordax, 122, 160-161, 166-167
Overpopulation, combatting, 19
Oxyethira sp., 310
Oxygen, relation to winter mortality, 23-33
toleration threshold, 32

P

Paludestrina, 308
Pantothenic acid, requirement of trout, 39-41
Perca flavescens, 27-30, 32, 64-65, 70-71, 110-114, 165-166, 304, 309, 312, 314
Perch, yellow, 27-30, 105, 110, 165-166, 174, 301, 304, 309, 312, 314
oxygen threshold, 32
rate of growth, 64-65, 70-71
sex ratio, 65, 70
Percina caprodes, 114, 304
Personnel, state fishery programs, 13-22
Petromyzon marinus, 123, 148-176
Phenacobius mirabilis, 208
Phillips, Arthur M., 34-45
Phosphorus, pond fertilizer, 346-348
relation to productivity, 327-328
Photograph, society, presentation, 401-403
Phryganea sp., 310, 312
Phycomyces blakesleeanus, 37
Phyllophaga sp., 312
Physa, 308
Pick, Lewis A., 361-368; (disc.), 368-372
Pickerel, DDT treatment, 316, 320
mud, 27-29, 301, 304
oxygen threshold, 32
Pike, 337
northern, 27, 29-30, 105, 113, 165-166, 301
oxygen threshold, 32
Pikeperch, yellow, 165-166, 173-174, 324, 328
Pimephales promelas, 209, 250, 317, 320-321
Pisidium, 308
Plankton, relation to productivity, 330
Planorbis, 308
Plantings, trout, 14-17
Plants, aquatic, relation to productivity, 330-331

  Anabaena, 350
  Anacharis, 345
    canadensis, 303
  Azotobacter, 349-351
  Carex, 342
  Ceratophyllum, 187, 345
    demersum, 303
  Chara, 249, 303
  Hydrodictyon, 187
  Hydrocotyle umbellata, 303
  Lactobacillus casei, 35
  Myriophyllum, 180-181, 345
    spicatum, 303
  Najas flexilis, 303
  Nelumbo, 187
    lutea, 184
  Nostoc, 350
  Nuphar advenum, 303
  Nymphaea odorata, 303
  Phycomyces blakesleanus, 37
  Potamogeton, 187, 345
    friesii, 303
    panormitanus, 303
    pectinatus, 180, 303
    zosteriformis, 303
  Ranunculus longirostris, 303
  Scirpus, 187
    acutus, 303
  Sparganium, 342
  Typha, 187, 342
  Veronica, 249
Plathemis lydia, 310
Plecoptera, 109
  Isogenus, 257
  Isoperla sp., 310-311
Poecilichthys exilis, 27, 32, 195, 197, 208, 304
Pollution, report of committee on, 425-432
  trout loss, 16
Polypedilum nubeculosum, 310
Pomolobus sp., 111
Pomoxis nigro-maculatus, 27-29 32, 65, 76-77, 178
Pond, culture, 19-20
  Europe, 336-339
  fertilization, 335-358
Population, estimation, 293-299
  Minnesota trout streams, 204-215
Potamogeton, 187, 345
  friesii, 303
  panormitanus, 303
  pectinatus, 180, 303
  zosteriformis, 303
Potassium, pond fertilizer, 344-346
  relation to productivity, 329-330
Presidents, list of past, 6-7
  opening remarks, 392-393
Pritchard, A. L., 4
Production, lake trout, 124-135, 143-146, 150
  whitefish, 150
Productivity, indices of lake, 322-334
Protozoa
  Chilodon, 18
  Octomitus, 16, 18
    salmonis, 94, 96
Pumpkinseed, 27-30, 304, 309
  oxygen threshold, 32
  rate of growth, 65, 72-73
  sex ratio, 72
Pungitius pungitius, 304, 309, 312
Pyrgulopis, 308

R

Rana, 111-114
Ranunculus longirostris, 303
Recruitment and yield, 287-288
Redhorse, 101, 165-166
Reid, Kenneth A., 5, 425-432
Rhagionidae, 109
Rhinichthys atratulus, 109, 111, 209-210
  cataractae, 208-210
Riboflavin, requirement of trout, 41
Rodd, James A., 5

S

Salmo, 109, 112
  gairdnerii, 34-45, 109, 112, 165-166, 179, 204-215, 290-314
  trutta, 34-35, 109, 111-112, 204-215, 304
Salmon, Kokanee, production, 16
Salvelinus fontinalis, 34-45, 82-96, 109, 112, 165-166, 204-216, 248-278, 280-300, 304
Salyer, J. Clark, 97-117
Schilbeodes mollis, 27, 304
Schultz, Leonard P., 4
Scirpus, 187
  acutus, 303
Scofield, W. L., 3
Sculpins, 111, 208
Semotilus a. atromaculatus, 109, 111-113, 166-167, 208-210, 304, 309
Severity, depletion, degrees of, 287-288
Sex ratio, bass, largemouth, 78
    rock, 74
    smallmouth, 80
  bluegill, 68
  cisco, longjaw, 243-245
  crappie, black, 76
  perch, yellow, 65, 70
  pumpkinseed, 72
Shad, forage fish, 47-48, 53-55, 61
Shetter, David S., 160-176, 248-278
Shiner, blackchin, 27, 304, 309, 312
    oxygen threshold, 32
  blacknose, 27, 250, 259, 304, 309
    oxygen threshold, 32
  common, 165-166, 304, 309, 312
  golden, 27-30, 47-53, 61, 304, 312
    oxygen threshold, 32
  mimic, 304, 308-309, 312
  spotfin, DDT treatment, 316-319
Shoemaker, Carl D., 3, 5
Sialis infumata, 310, 312
Silversides, Brook, 27, 304
Simon, James R., 3, 398-400, 433-434; (disc.), 443
Simulium venustum, 310-311
Sloan, William G., 373-378; (disc.) 379
Smelt, 160-161, 166-167
  mortality, 122-123
Smith, Lloyd L., 4, 204-215, 279-282
Smith, M. W., 5
Snake, 111
Snow, relation to winterkill, 27
Snieszko, S. F., 82-96
Sodium arsenite, weed control, 178-179
Sparganium, 342
Sphingidae, 312
Spiders, 305-308
Staphylinidae, 109
State, fishery program, 13-22

Stickleback, 105, 111
  brook, 250, 259
  ninespine, 304, 309, 312
Stizostedion v. vitreum, 165, 322-330
Stratiomyidae, 109
Stocking, bluegill fry, survival, 190-203
Stoneroller, 208
Stylurus sp., 310
Sucker, 105, 156
  chub, DDT treatment, 316, 318-319
  common, 165-166, 173-174
  stoneroller, DDT treatment, 315, 318-320
  white, 206-207, 209-211, 304
    DDT treatment, 316, 318-320
Sufamerazine, dosage in furunculosis treatment 82-96
Sulphate, relation to productivity, 326
Sunfish, 105, 111
  green, 193-195, 197, 304, 309
    DDT treatment, 318-319
  longear, 202
  yellow-bellied, DDT treatment, 318-319
Surber, Eugene W., 315-321
Survey, trends in state fishery programs, 13-22
Survival, bluegill fry plantings, 190-203
  furunculosis treatment, 87, 92-93
Swingle, H. S., 46-62; (disc.), 431

T

Tanypus stellatus, 310
Tanytarsus jucundus dimorphus, 310
Tetragoneuria simulans, 310
Thiamin, requirement of trout, 41-43
Tipula abdominalis, 310
Toleration threshold, oxygen, 32
Topminnow, 105
  blackstripe, 27
Toxicity, DDT to fish, 315-321
Trematoda
  Gyrodactylus, 16-18
Triaenodes injusta, 310
  tarda, 310
Trichlorbenzene, weed control, 179
Trichlorethylene, weed control, 181
Trichoptera, 109, 112, 257
  Banksiola selina, 310
  Brachycentrus sp., 310
  Helicopsyche, 109, 310
  Leptocella albida, 310
    exquisita, 310
  Mystacides sepulchralis, 310
  Oecetis eddlestoni, 310
  Oxyethira sp., 310
  Phryganea sp., 310, 312
  Triaenodes injusta, 310
Trout, 105, 109-110
  brook, 165-166, 304
    effects of deflectors on angling, 248-278
    populations, Minnesota, 204-215
    production, 16
    treatment of furunculosis, 82-96
    vitamin B requirement, 34-45
    yield, 290-300
  brown, 304
    populations, Minnesota, 204-215
    production, 16
  vitamin B requirement, 34-45
  culture, statistics, 14-18
  cutthroat, production, 16
  lake, abundance, 135-139, 143-146
    catch, 136-139, 143-146
    feeding habits, 301-314
    fishery, 121-147
      intensity, 139-146
    production, 16, 124-135, 143-146, 150
  rainbow, 165-166, 179
    feeding habits, 301-314
    populations, Minnesota, 204-215
    production, 16
    vitamin B requirement, 34-45
    yield, 290-300
Tucker, William J., 4
Turtle, egg, 113
Typha, 187, 342

U

Ulcers, trout disease, 16
Umbra limi, 27-29, 109-110, 112-113, 250, 304
Utilization, fish stocks, 285, 287-288

V

Valvata, 308
Van Oosten, John, 3, 283-289; (disc.), 379, 388; 392-393; (disc.), 444
Veronica, 249
Vitamin B, requirement of trout, 34-45

W

Warmouth, 27
Washburn, George N., 23-33
Water, quality, classification, 326-327
    relation to productivity, 324-330
  mites, 305-308, 312
Weed control, 177-182
Westerman, Fred A., 4; (disc.), 369, 417; 440-442; (disc.), 443
Whitefish, 173-174
  production, 150
Whiteleather, R. T., 118-120
Wickliff, E. L., 4
Willard, (disc.), 368
Williams, (disc.), 372
Winterkill, Michigan lakes, 23-33
  pondfish, 19
  trout, 16
Wire, Frank B., 4

Y

Yield, analysis, 291-293
  per unit effort, 286-287
  pikeperch, 324, 328
  reduced total, 286-287

Z

Zygoptera, 109